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Abstract: While the commercial trade between regions and nations has always been the subject of regional economics, the realization that environmental issues can be examined in a regional economic context is more recent. This study thus attempts to provide an overview of the major issues concerning economic interactions between environmental and trade policies. Such a review is necessary because of the pressure that the accelerated pace of globalization is placing on environment and trade. Not only is world trade increasing rapidly, but global industrialization related to trade and regional economic growth has spawned severe environmental degradation. As a consequence, growing numbers of researchers have attempted to analyze the linkages between these areas. This paper attempts to provide a perspective on received and future research by employing a dual approach: economic studies of the major environmental and trade issues are analyzed first; and then progress in the methods necessary to analyze their interactions is assessed second. The conclusions suggest new possibilities for research design and policy goals.

ENVIRONMENT AND TRADE:

A REVIEW OF ISSUES AND METHODS

1. INTRODUCTION

It has been widely accepted that economic globalization is here and that global trade plays an increasingly important role in determining relative economic growth among countries. International trade has grown considerably in recent decades. For example, over the period 1979 to 1991, world real export growth averaged 4.4 percent per year, while real output expansion averaged only 2.9 percent per year [Markusen et al. 1995]. Since 1990, the average growth of international trade has exceeded 6 per cent, while world merchandise output growth has averaged only 3 per cent, confirming that globalization is continuing at a rapid pace [WTO 1996]. World integration is thus being accelerated through international trade in goods, services, resources and capital. Not only can trade help to optimize the utilization of global resources but it can benefit all participating countries. This realization has caused the General Agreement on the Tariffs and Trade (GATT) to evolve into the World Trade Organization (WTO). In addition, free trade zones have been expanding. More European countries now belong to the European Union (EU), and the United States, Canada, and Mexico have created the North American Free Trade Area (NAFTA).

This growth in trade has influenced the quality of the environment principally in exporting but also in importing countries. The notion that free trade among countries leads to welfare maximization becomes questionable, when environmental degradation lowers that welfare. While comparative advantage implies that a country might specialize in the production of a pollution intensive commodity, such pollution would cause the environmental quality of the country to deteriorate. In this case there is a trade-off between gains from trade and environmental deterioration in this country, compared to a country producing non-polluting goods, since income will increase only if gains from trade overcompensate welfare losses from environmental damage. Stricter environmental policies in the first country would thus affect its comparative advantage and consequently its economic growth.

Such interactions between trade and the environment have produced an increasingly greater need for a careful and balanced assessment of the issues involved and the challenges they pose to policy makers. Investigation of the interactions between trade and the environment can be traced back to the early 1970s and was stimulated by the first United Nations Conference on the Human Environment in 1972. Some earlier studies tracing this history include Baumol (1971), Blackhurst (1977), GATT (1971), Pethig (1976), Siebert (1973), Markusen (1975), and Walter (1975, 1976). Since the 1980s, concerns about increasing world economic development, trade liberalization, and environmental stabilization have become globally important. This reflects the growing recognition of the global impact of industrial development and related problems of environmental deterioration on sustainable development. Worldwide attention to these issues can be found in works of Anderson and Blackhurst (1992), Beghin et al. (1994), Bhagwati (1993), Dean (1992), Low (1992), Muzondo et al. (1990), Siebert et al. (1980), and Jaffe et al. (1995), among others.

Today the above issues linking environment and trade have expanded broadly; they can classified with some omissions into at least five categories:

(1) effects of environmental policies or regulations on comparative advantage, specialization, industrial redeployment, trade patterns and terms of trade;

(2) effects of trade on environmental quality and welfare, and the use of trade policies for environmental purposes;

(3) use of environmental policy measures as strategic trade instruments to protect industries and stimulate growth;

(4) coordination of the sometimes conflicting objectives of trade policy and environmental policy; and

(5) control of transboundary pollution, including trade in wastes.

Because of the diversity and complexity of these issues, it has proven difficult to organize and to analyze them as a single area of concentration. Consequently few major surveys can cover all of them in a comprehensive manner. Among reviews that have proven useful are those by Dean (1992), de Boer (1994), Ulph (1994), van Beers and van den Bergh (1996), and Xing and Kolstad (1996). As examples, Dean (1992) provides an insightful survey of the empirical literature and focuses principally on issues in the first and the fifth category. De Boer (1994) surveys some important theoretical issues arising mainly in the first two categories. Ulph (1994) offers a useful technical review of traditional analysis and imperfectly competitive games, addressing the interactions between environmental policy and international trade in the framework of strategic trade policy. Van Beers and van den Bergh (1996) contribute a valuable overview of the methodological approaches, principally the Heckscher-Ohlin model and equilibrium type of economic models, which underlie theories of international trade when environment is taken into account. Xing and Kolstad's (1996) survey is similar to that of Dean (1992), but covers empirical studies as well as theoretical results, including a wider range of issues on environmental regulation and international trade. Clearly, though each of these surveys provides a valuable step forward, they tend to emphasize particular aspects of the total area and already are date limited.

The present effort thus attempts to provide a more comprehensive survey of this area. However, we do realize the limitations involved to achieve such a result. The approach taken has been to evaluate studies linking trade and environment from a dual perspective. The first step has been to summarize and to analyze various studies according to the major topics or policy issues surrounding interactions between trade and the environment. As shown in Table 1, these topics and issues have been organized to include: (1) the nature of macroeconomic impacts, (2) patterns of trade and comparative advantage, (3) terms of trade, (4) patterns of production and consumption, (5) linkages between trade, environment and the economy, (6) pollution redeployment to developing countries, (7) environmental degradation, and (8) factor rewards.

The second step has been to review the various methodologies or quantitative approaches that have been applied to evaluate the above issues. A summary of these approaches provided in Table 2 consists of the following: (1) computable general equilibrium models, (2) international trade models, (3) input-output models, (4) welfare analysis models, (5) game theoretic models, (6) optimization models, (7) spatial GIS models, and (8) econometric models.

Table 1

ISSUES CONCERNING ECONOMIC INTERACTIONS BETWEEN ENVIRONMENT AND TRADE

1 Macroeconomic Impacts
- Impacts on National Income
- Impacts on Employment
- Impacts on Other Economic Variables
- Impacts on Balance of Trade and Payments
- Impacts on Sustainable Development

2 Patterns of Trade and Comparative Advantage
- Patterns of World Trade in Environmentally Sensitive Goods
- Comparative Advantage

3 Terms of Trade
- Impacts of Emission Standards in One Country
- Impacts of Pollution Taxes in One Country
- Transnational Pollution case

4 Patterns of Production and Consumption
- Structural Change of Production Sectors
- Impacts on Production—Supply Side
- Impacts on Consumption—Demand Side

5 Linkages between Trade, Environment, and the Economy
- Conflicts between Trade Policy and Environmental Policy
- Transnational Pollution and Trade
- Natural Resources and Trade
- Hazardous Substances and Trade
- Global Warming and Trade

6 Pollution Redeployment to Developing Countries
- National Environmental Policy and Capital Mobility
- Environmentally-Induced Industrial Relocation

7 Environmental Degradation
- Trade and the Global Environment
- Trade Induced Environmental Degradation

8 Factor Rewards
- Capital and Labor Rewards
- Resource Rewards

Table 2

METHODS FOR ANALYZING INTERACTIONS BETWEEN ENVIRONMENT AND TRADE

1 Computable General Equilibrium Models
 CGE Models
 Non-Market CGE Models
2 International Trade Models
 The Heckscher-Ohlin Model
 Empirical Trade Models
3 Input-output Models
 I-O Models, Multipliers and linkages
 Trade and I-O Models
 Environmental I-O Models
4 Welfare Models
 Welfare Analysis and Impact Measurement
 Welfare Analysis of Gains from Trade
 Welfare Analysis of Environmental Policy
 Impact of Environmental Policy on the Net Benefits from Trade
5 Game theoretic Models
 Cooperative game Theoretic Models
 Noncooperative Game Theoretic Models
6 Optimization Models
 Searching for Optimal Trade and Environmental Policies
 Lack of Applications
7 Spatial GIS Models
 Spatial Analysis
 GIS Model Theory
 GIS Model Applications
8 Econometric Models
 Trade and Environment Linkages over Time
 Potential Applications

In both parts, the attempt has been not only to review past theoretical and quantitative approaches but also to suggest new areas where the approaches can be applied. For example, geographic information systems and econometric methodologies have been applied less than what one would expect. New possible applications are thus interjected. Accordingly the conclusions drawn from this survey are intended to stimulate further theoretical and quantitative research on important problems in this area.

2. ISSUES CONCERNING ECONOMIC INTERACTIONS BETWEEN ENVIRONMENT AND TRADE

2.1 Introduction

Economic interactions between environmental and trade polices concern the effects that these policies have on resource allocation, income distribution, and environmental consequences, both among and within trading countries. Economic analysis of these interactions treats environmental and trade policies as having both positive and negative consequences, depending on the economic mechanism involved. Our survey of these many different topics or areas that studies have analyzed suggests that the following questions are most frequently addressed: (1) What are the macroeconomic impacts of environmental trade policies? (2) How do these policies determine the patterns of trade and comparative advantage? (3) What are the implications of these policies for patterns of production and consumption and returns to factors? (4) How do environmental policies affect terms of trade? (5) What is the relationship between trade, environment, and the economy? (6) Does trade result in environmental degradation? In this section, we evaluate studies aiming to answer these questions, focusing on the economic theories that provide insights and possibilities for making policy recommendations.

2.2 Macroeconomic Impacts

2.2.1 Impacts on national income

The impacts of domestic environmental control policies on national income were first assessed by D'Areg (1971). For example, if environmental policies in the form of effluent charges are imposed on individual firms, the impact on comparative advantage will usually arise from two sources. First, substitution of relatively cheaper imports for domestic commodities will decrease the level of domestic production and, thus, domestic income. Second, these initial shifts in domestic demand and income through multiplier effects will result in further adjustments in domestic income and imports. Using the trade model, D'Areg estimated such domestic income effects resulting from changes in export prices due to the imposition of domestic environmental policies. He found that the impact on domestic income stemming from international feedback effects was negative and came primarily through impact multipliers.

Using general equilibrium models that include trade between countries, Siebert et al.(1980) also analyze the effects of domestic environmental policies on national income. They consider two cases: one is that the home country is small, which implies a given relative price for the home country; and the other is the two-country case, which implies that the home country is no longer a small country, but it affects its relative prices *vis a vis* the world market. Assuming non-inferior commodities and based on a two-sector economy model, they conclude that environmental policy will reduce resources used in an emission-intensively producing sector and in production activities in both sectors. Resource use in abatement will increase. This holds for both the small- and the two-country case. For a given relative commodity price, national income will decline. If the relative price is variable, national income will decline when either the emission intensity of a sector is relatively high or when it has a high price elasticity of demand.

Many other studies, also reveal the negative effects of environmental policies on national income, e.g. Manne and Richels (1991a), (1991b), and (1992); Manne (1992);

Dervis et al. (1982); Rose et al. (1994); Yao et al. (1994); and Zhang (1998). The economic theory implied in those studies is that pollution abatement policies reduce production and thus decrease national income. However, when we talk about the negative impacts of environmental policy on national income, we should also keep in mind that this does not mean a definite decrease in welfare. Due to the implementation of environmental policies, the supply of environmental goods increases; however, to a large extent, their impacts are not considered in national income account evaluations. In addition the production of pollution abatement equipment can offset losses in industrial production due to more stringent environmental standards.

2.2.2 Impacts on Employment

There has been substantial debate and confusion about whether environmental policies do or do not influence domestic employment (Hopkins 1992). So far it is difficult to come to any precise conclusions, though at least in the short run, negative effects caused by a cutback in production will lead to a considerable decline in employment (Zhang 1998). However, in the long run, environmental policies will result in investment in pollution control equipment and thus create more employment opportunities. According to the OECD (1985), with few exceptions employment levels rise with pollution-control expenditure, particularly under some variants in the United States, France and, especially, Norway. The counterpart of this result is an implicit worsening of productivity growth. This occurs because national income growth rates are either somewhat lower, or only slightly higher, than they otherwise would have been, while labor inputs increase because of environmental measures.

2.2.3 Impacts on Other Economic Variables

Denison (1979) and Crandall (1981) show that environmental regulations adopted in the 1970s have a negative effect on U.S. productivity growth. Investigations on five OECD countries reveal that productivity levels are usually lower than they would have been without environmental programs (OECD 1982). However, the validity of these results is weakened by the underlying assumption that environmental policies increase production costs since capital and labor invested to comply with environmental policies do not contribute to measurable output, nor do the efforts required for paperwork and legal formalities of compliance. Many empirical studies show that, in general, the impact of environmental polices on industrial production costs is very small because pollution abatement costs constitute a very small portion of industrial costs on average, e.g. see Tobey (1990), OECD (1985), Smith and Ulph (1982), and Jaffe et al.(1995). Moreover, in some industries the implementation of environmental policies is accompanied with positive productivity effects. For instance, pollution reduction with energy saving and material recovery may lower the unit cost of production and increase product sales because in some cases recovered materials can be profitable by-products. Recent wisdom is that environmental policies induce "more cost-effective processes that both reduce emissions and the overall cost of doing business……"(U.S. Environmental Protection Agency 1992). Porter and Linde (1995) further point out that, from a dynamic view, environmental regulations provide incentives for technical innovation and hence in some industries productivity will rise in response to "properly crafted environmental regulations".

The impact of environmental protection costs on product prices also has received attention, e.g., Pasurka (1984), Mutti and Richardson (1977), Walter (1973), Robinson (1988). Most studies of this kind utilize an input-output framework and assume that all costs pass through into prices. The price changes caused by environmental policies can be derived simply by multiplying the abatement cost vector by the standard total requirements matrix. Robinson (1988) argues that the assumption of full-cost pass-through into prices is reasonable in the long run. He also points out that greater than full-cost pass-through is possible in oligopolistic industries, while in highly competitive industries, price increases smaller than cost increases might occur. Moreover, the use of the full-cost pass-through assumption helps ensure that the estimates of the price change are, in fact, upper bounds.

2.2.4 Impacts on Balance of Trade and Payments

Among the contributions to the impact of environmental policies on the balance of trade and payments, works by Baumol and Oates (1975) and Robinson (1988) are important. Based on a two-final-good model, Baumol and Oates (1975) analyze the trade impacts of industrial pollution abatement costs and derive the balance of trade conditions for a two-good two-country world. In doing so, one good has pollution associated with its production, while the other does not. According to this model, only direct abatement costs have an impact on prices and thus on the balance of trade and payments. Robinson (1988) extends Baumol and Oates's (1975) two-good model to a seventy-eight sector model with all interindustry effects considered. Using this extended model, Robinson applies an ex-post partial-equilibrium method to measure the impact of marginal changes in industrial pollution abatement costs on the U. S. balance of trade in general, and on the balance of trade with Canada in particular. Robinson's work shows that environmental policy has a significant negative effect on the balance of trade, if environmental costs are fully reflected in commodity prices.

2.2.5 Impacts on Sustainable Development

As is well known, free trade policy is designed to allow markets to allocate resources according to their most efficient uses, while environmental policy seeks to manage and maintain the earth's resources efficiently. Though conflicts may arise where the same resources are subject to both trade and the environmental purposes, "on the most fundamental level, trade and environmental policy must meet in the concept of sustainable development. Both trade policy and environmental policy must serve that concept as their ultimate goal." (EPA Trade and Environment Committee 1991).

Hudson (1993) provides a useful starting point from which to examine the issues related to trade, environmental policy, and sustainable development. He begins with a philosophical approach to trade and environment. He argues that an environmental perspective on trade should not be construed as anti-trade, since trade can be an important instrument with which to achieve development that is economically and environmentally sustainable. He points out that in the long run environmental policy will not be successful if it ignores the development needs of the world's poor; and on the other hand, the benefits of a more liberalizing trading system cannot be sustained over the long-term, if environmental and natural resources considerations are not taken into account.

The impacts of trade liberalization and globalization on sustainable development have been examined by recent empirical case studies, i.e., Dragun and Tisdell (1999) and Jha, Markandya, and Vossenaar (1999). Though trade liberalization and world economic globalization portend an international “win-win” situation, those studies find that there is substantial evidence to suggest that trade liberalization and globalization appear to have a negative impact on agricultural sustainability in developing countries. In order to achieve sustainable development, to reconcile trade and the environment is the key. Moreover, special attention needs to be paid to local issues in poor countries in the face of trade liberalization and globalization.

2.3 Patterns of Trade and Comparative Advantage

2.3.1 Patterns of World Trade in Environmentally Sensitive Goods

Economic analysis would suggest that environmental policies raise production costs and hence encourage reduced specialization in the production of polluting outputs in countries with more stringent environmental regulations, e.g. Pethig (1976), Siebert (1977), McGuire (1982). That is, countries with less stringent environmental policies could increase their comparative advantage in the production of environmentally sensitive goods. However, this standard trade theory is challenged by a more recent revisionist view. Porter and van der Linde (1995) argue that tight environmental policies are actually positive forces driving private firms and the economy as a whole to become more competitive in would markets by spurring innovation in environmental technologies. These conflicting views have since then led to a heated debate, i.e. see Stewart (1993) for an overview.

Tobey (1990, 1993) approaches this problem empirically by examining environmental policy and patterns of world trade. Following earlier studies on shifting patterns of international trade by Leamer(1984) and Bowen (1983), Tobey employs a cross-section Heckscher-Ohlin-Vanek (HOV) model to test the hypothesis that the stringency of environmental policies is directly related to the exports of pollution-intensive commodities. Pollution-intensive commodities are defined by Tobey as the products of those industries whose abatement costs in the United States are equal to or greater than 1.85 percent of total costs. According to this criterion, among the 64 agricultural and manufacturing commodities under investigation, 24 of them are labeled as pollution-intensive commodities. Using econometric methods, Tobey aggregates the 24 commodities into five groups and regresses the net exports from each group on US endowments of 11 resources and a dummy variable which indicates the stringency of a country's environmental policies. The statistical results indicate that there is no significant linear relationship between the stringency of environmental policy and the net exports of the pollution-intensive commodities. That is, environmental policy has no significant impact on patterns of world trade. Tobey also tests the impact of environmental policy on trade patterns by investigating the bias in the regression residuals when the variables representing countries' environmental endowments are not included in the HOV model. If environmental policy does have an impact on net exports, then countries with stringent policy should have a negative expected sign in the error term, while the residuals of the countries with lenient policy should be positive. By examining the residuals, however, Tobey finds no assumed distribution of the error terms and thus concludes that the impact of environmental policy on world trade patterns is not significant.

2.3.2 Comparative Advantage

According to classical trade theory, a country's comparative advantage stems from differences in technologies and in factor endowments (as compared with the respective conditions of its trading partner). That is, a country may have a comparative advantage if a country has technology by which it can produce a product with relatively low cost, or it is rich in certain resources. Since the 1970s, numerous theoretical studies have tried to examine the impact of environmental policy on comparative advantage, e.g. see Siebert (1977), Siebert and et al (1980), Pethig (1976), McGuire (1982), Baumol and Oates (1988), Krutilla (1991), Carraro and Siniscalo (1992), Brander and Taylor (1997), and Markusen (1997).

Siebert and his co-authors (1980) have employed a two-commodity-two-country model to investigate possible different technologies as determinants of comparative advantage. Their major result confirms the intuitively expected result that a country's technological comparative advantage to produce less pollution-intensive goods is strengthened by environmental policy. In addition, if one country has a technological comparative advantage for pollution intensive goods before trade, it can overcompensate this advantage by adopting a sufficiently stringent environmental policy. That is, if a country exports and specializes in a pollution intensive good and if it has appropriate technologies, it generally can switch its trade flows by enforcing a sufficiently stringent environmental policy. This group also investigates comparative advantage stemming from differences in relative factor abundance, which include divergences in the quality of resource endowments and in demand conditions. The most interesting feature of their analysis was to treat a country's emission standards as a factor endowment. With this interpretation, they apply the traditional Heckscher-Ohlin-Samuelson theory of pure trade to the case of two countries, both of which implement an environmental price and standards system. They then point out that, given certain qualifications, even the Factor-Price-Equalization theorem applies insofar as the two countries' relative emission taxes equalize in a trading equilibrium, even though both countries pursue stringent environmental policies in different ways.

Baumol and Oates (1988) also confirm conventional views on this issue. In their model, both countries produce an identical traded good and its production generates pollution in both countries. Using partial equilibrium analysis, Baumol and Oates demonstrate that if a country does not impose environmental policy when the other country does, then the first country will increase its comparative advantage or decrease its comparative disadvantage in the pollution-intensive industry, and it will then specialize in that industry at the cost of environmental degradation.

Brander and Taylor (1997) more recently examine the question of whether countries with 'low standard' (LS) resource management policies might have a comparative advantage over countries with 'high standard' (HS) resource management policies. They construct a trade model between an LS country (countries possessing weak resource management) and an HS country (countries possessing rational resource management). Both countries are endowed with an identical renewable natural resource and both countries are identical except for their resource management policies. Using general equilibrium analysis, Brander and Taglor demonstrate that with no trade (autarky) there are two steady-state harvesting rates for the LS country: mild overuse and severe overuse. With the introduction of trade between the two countries, in the mild overuse case the LS country has a comparative advantage and thus is a net exporter of the resource good in steady state. This result confirms the received view on the relationship between environmental policy and comparative advantage. However, in the case of 'severe overuse' in autarky, the LS country becomes a steady state importer of the resource good after trade opens. The result in this case contradicts the received view.

As mentioned before, Porter and van der Linder (1995) challenge the received view relating environmental policy and comparative advantage by arguing that comparative advantage does not depend on static efficiency or on optimizing within fixed constraints; rather it is a function of the capacity of a firm to initiate innovation and improvements in order to shift those constraints. Moreover, tight environmental policy can, at times, act as an incentive to domestic firms with a strong home base to create a first mover-type of comparative advantage. Since such contradicting views result from applying theory alone, empirical studies can play a role in settling such disputes by measuring both the magnitude and sign of the impact of environmental policy on comparative advantage. However, so far the empirical results have been ambiguous, i.e. Ugelow (1982), Tobey (1990), and Jaffe et al. (1995).

2.4 Terms of Trade

2.4.1 Impacts of Emission Standards in One Country

According to trade theory, a change in terms of trade may increase or lower the social cost of attaining a given target of environmental quality from what it would have been if the terms of trade had remained constant. Therefore, it is worthwhlie to examine whether a country will be able to share its costs of the imposition of environmental policies with the rest of the world *via* a terms-of-trade improvement. Siebert and his co-authors (1980) investigate the analytical links between alternative levels of the emissions standards in a country and any possible resulting changes in terms of trade.

Again Siebert and his co-authors use the well-known two-country model of trade as their framework of analysis. They assume that the home country undertakes an emissions standard policy while the rest of the world employs no environmental policies and that environmental policy, affects comparative costs in the case of a binding emissions standard. By means of comparative statics, they prove that free trade with direct pollution control in the form of an emissions standard policy enables the acting country to improve its terms of trade, if the production of the exportable good is relatively emissions intensive. They argue that the initiation of a pollution control policy of the home country decreases the relative abundance of the good affected by the policy and, in order to equalize world demand and output, the relative price of the good has to increase. The home country's terms of trade will improve because its total output will be smaller, while that of the foreign country remains unchanged. They interpret this result as signifying that trade enables a country which undertakes an environmental policy to transfer a share of its real costs of pollution control generated entirely within its own borders to the rest of the world. In the opposite case where the import is relatively emissions intensive, they obtain a deterioration effect of the terms of trade, which implies an additional component of social cost to achieve the policy goal. However, just as the authors themselves point out: in reality the trading partner would also undertake a control policy so that the outcome on terms of trade must be reinterpreted. A formal analysis of this case would be much more complicated.

2.4.2 Impacts of Pollution Taxes in One Country

Magee and Ford (1972) provide a fruitful analysis of the implications of alternative pollution abatement taxes for the terms of trade in the United States. The authors divide the U.S. economy into an import sector and an export sector and then set up a simple four-equation model of the demand for imports into the United States and the supply of imports from abroad. Throughout, the authors use partial equilibrium analysis, i. e., import and export price changes are assumed to be independent.

According to Bhagwati (1971), a production tax is the most efficient solution to controlling production pollution, while a consumption tax is the optimal response to consumption pollution. Using this principle, Magee and Ford (1972) first examine the consequences of government taxation to combat either production or consumption pollution in the import sector. They demonstrate that if pollution occurs at the production level, a production tax on U.S. import-competing production will unambiguously result in an increase in the quantity, the price and in the value of U.S. imports. This leads to deterioration in the U.S. terms of trade. In the case of pollution derived from goods consumed in the import sector, if U.S. imports are complementary to domestic non-import-competing production, then the consumption tax increases the price, the quantity and hence the value of the import. Again, the U.S. terms of trade deteriorates. If, on the other hand, U.S. imports are substitutes with domestic non-import-competing production, then the consumption tax reduces the quantity, the price and the value of U.S. imports; this means that the consumption tax improves the U.S. terms of trade.

Magee and Ford then turn to a similar analysis of the case where pollution occurs in the export sector. Their results show that if a production tax is imposed on the export sector, export prices and the price of domestic goods will increase and hence the tax improves the U.S. terms of trade. If a tax is levied on domestic consumption of the exportable product in the United Stated, the authors illustrate that the U.S. terms of trade will deteriorate (improve), if exporter marginal costs are increasing (decreasing). The results are less clear in this case since it is difficult to empirically decide whether costs are increasing or decreasing for the U.S. exporters.

There appear to be no studies explaining how pollution taxes influence the terms of trade of the developing countries.

2.4.3 Transnational Pollution Case

Due to the spatial characteristics of the environment, transnational pollution issues (for example, acid rain and the pollution of the Great Lakes or industrial pollution and the Rhine river) have inevitably become a serious problem for governments throughout the world. The solution to this problem usually requires that the countries involved adopt some abatement strategies appropriate to control transborder pollution.

To examine the impact of these strategies on terms of trade, Merrifield (1988) constructs a two-country general equilibrium (GE) trade model with pollution and introduces two abatement strategies, production taxes and the abatement equipment standard. Merrifield's model represents an advance over previous work (e.g. McGuire 1982), in this area that pollutants, goods, and capital are internationally mobile, and prices of factors, goods and terms of trade are determined endogenously. The key to this analysis is the impact of abatement strategies on prices, and hence on the movement of goods and productive resources between the trading countries. By means of comparative static analysis, Merrifield finds that, in general with internationally mobile goods, capital, and pollutants, the comparative static results are ambiguous, except that the abatement equipment standard strategy has an unambiguous impact on pollution flows. He thus employs the model to analyze the impact of abatement strategies in the context of the acid rain deposition problem between the U.S. and Canada.

Merrifield illustrates that if the two countries jointly and simultaneously levy a production tax, production in both countries will not be altered and, consequently, the terms of trade will not change. Similarly, if both countries agree to raise their abatement equipment standards, there will be no change in the terms of trade if the elasticity of substitution of capital for labor is similar in the two countries. He also demonstrates that if Canada adopts a stricter abatement standard, the terms of trade will be shifted in Canada's favor. However, since much attention is paid to the analysis of the effect of abatement strategies on transnational pollution, many related questions, such as how a country's production tax influences the terms of trade or whether a country with a stricter abatement standard can improve its terms of trade, are not fully explored.

2.5 Patterns of Production and Consumption

2.5.1 Adjustments in Production Sectors

Environmental protection policies may lead to sectoral structure distortion in the conservationist country. This distortion is reflected by changes in product prices and in sectoral production. In general, with the imposition of environmental protection costs in one sector, the product price of that sector will increase and the rise in product price tends to be spread over the whole economy. Similarly, a reduction in emissions of certain pollutants may cause a change in sectoral production.

Utilizing a partial equilibrium input-output framework, Pasurka (1984) analyzed the magnitude of the impact of environmental protection costs on U.S. product prices in 1977. The advantage of the input-output framework is that the effects of the abatement costs that are passed along in the form of higher prices of intermediate goods can be observed. In his analysis, Pasurka divides the US economy into 79 production sectors. Pasurka's study reveals that the total percentage increase in product prices ranges from 0.12 percent for real estate and rental to 6.58 percent for electric, gas, water and sanitary services. The average weighted price increase is found to be 0.97 percent. This result shows that for most U.S. industry sectors, environmental protection costs do not result in significant price increases. However, the accuracy of the result is discounted by several of the assumptions made in order to conduct the input-output analysis. In particular, the assumption of fixed input-output coefficients, when there are changes in relative prices due to environmental protection costs, leads to imprecise results.

By means of a CGE model, Zhang (1998) empirically investigates the impact of CO_2 emission limits on China's sectoral production. According to Zhang, aggregate gross production tends to contract at an increasing rate as carbon dioxide emission targets become more stringent. However, changes in sectoral gross production differ significantly among sectors in both absolute and relative terms. For example, under the scenarios that China's CO_2 emissions in 2010 will be cut by 20 and 30 percent respectively, the coal sector is affected most severely; its gross production falls by as much as 26 and 38 percent accordingly. To the contrary, the gross production of the agricultural sector is the least affected, it falls by only 0.49 and 0.28 percent respectively. In contrast to these negatively affected sectors, gross production increases are observed for the service sector. Moreover, its expansions rise at an increasing rate as CO_2 emission reduction become greater (1.71 and 5.53 percent in the two scenarios respectively). The results indicate that, given reductions in CO_2 emission, an economy will restructure toward labor-intensive sectors.

2.5.2 **Impacts on Production**

The literature on environmental supply impacts has been inconclusive. According to Leontief's (1970) input-output study, in a closed economy, assuming that the elimination of pollution can be achieved by use of intermediate products from sectors other than anti-pollution and that final deliveries to households remain constant, the output of all the productive sectors clearly will increase. Moreover, the more complete the elimination, the greater the magnitude of the increase. Siebert, Eichberger, Gronych and Pethig (1980) have studied the impacts of an emission standard on the supply side of a closed economy using a two-sector-two factor model. When a given commodity price ratio is assumed, the authors conclude that the restriction of the emissions standard reduces the output of the relatively emissions intensive sector and increases the output of the other sector. The authors further examine changes in relative commodity supply and show that the restriction of an emissions standard brings about a rise in the output of the capital intensive (labor intensive) sector, if it is much more difficult to substitute capital (labor) in both sectors against emissions than the other factor. However, the impact of the restriction on the total production of the economy is not discussed.

The OECD (1985) investigates the effects of various environmental programs on the levels of GDP in selected OECD countries. Its finding shows that a period of initial GDP growth (0.1 and 0.2 percent in the Netherlands and the United States respectively) is followed by a decline during the final program year and beyond (up to –0.7 and –1.1 percent). The GDP trend indicates that production is affected by environmental program via two forces. The first force is generated by additional demands for goods and services. The installation of pollution controls increases capital investment and the services required to operate it. The second force is created by the multiplier and accelerator effects of these additions to demand. Both forces interact to promote production expansion in the early years of the programs. Over time, however, the expansion places pressure on the utilization of productive capacity and hence on costs and prices. Rising costs and prices begin to offset the favorable impact on production. And, when the programs are over, only negative price effects remain, and production levels fall below those without environmental programs.

2.5.3 Impacts on Consumption

There are also few studies that analyze how environmental policy influences consumption. Using macro econometric models, the OECD (1985) examines the impact of environmental protection programs on the aggregate demand components of some of its member countries. They found that four out of five case studies showed that in the final year of a pollution control program, total private consumption decreased only slightly, from 0.1 per cent in France to about 1.0 percent in the Netherlands and the United States, compared to consumption without the program. This decrease is caused by factors such as the impact of additional costs on consumer prices, and the rapid reduction of favorable multiplier effects on disposable income induced by taxation in some programs. Only in Norway does private consumption rise (by 0.3 per cent after the first few years and 0.7 per cent in the final year) as a result of environmental programs.

Usually, the impact of abatement costs on prices has an unfavorable effect on real consumer spending. In the Norwegian case, however, this is more than offset by a higher overall level of activity leading to favorable multiplier effects on employment and household income. In addition all studies they reviewed report a slight decline in exports of goods and services (by 1 percentage point or less in the final year of a program) due to the adoption of environmental programs. Finally, the effects on private non-residential investment differ widely from study to study. While a negative effect is observed in the Netherlands, in the Finnish, French, and the U.S. studies, environmental programs lead to an increase in private non-residential investment. However, what causes this difference among these studies is not explored.

2.6 Linkages between Trade, Environment and the Economy

2.6.1 Conflicts between Trade Policy and Environmental Policy

The basic objective of trade policy is to liberalize international trade and to attain the benefits of comparative advantage. Taking this advantage usually leads a country to specialize in the production of goods and services that it can produce more efficiently. Accompanying the process of specialization, however, environmental problems may arise due to the externalities of specialization. In order to solve those problems governments often have to provide certain kinds of environmental regulations or incentives that to some extent either clash with trade policies or alter them significantly. The conflicting relationship between trade and environmental policies has received both an economic and a political focus since the 1990s, e.g. see Housman and Zealke (1992), Jackson (1992), and Saunders (1994).

Audley (1997) points out that the conflicts between trade and environmental policy often involve the competitive differences between national and international environmental policies. Business leaders from multinational firms worry that competition with manufacturers operating in countries where they are not required to internalize similar environmental costs may enjoy price advantages created by such policy. On the other hand, developing countries argue that trade policies that require imports to meet domestic environmental standards effectively restrict access to larger markets, e.g. Snape (1995), Pearson (1993), and McAlpine and Le Donne (1993). The rise in non-tariff barriers reported by the WTO sparked concern that environmental policy would become a new form of non-tariff protection (Runge 1990, 1993). Under the guise of environmental policies, foreign products might be prohibited from access to markets where domestic products are more expensive (Snape 1995, and Stokes 1992). Policy standards such as auto emissions, agricultural regulations controlling pesticide residue, or product component quality, have been criticized by trading countries that believe these policies are designed to restrict market access for foreign products under the guise of insuring food safety or promoting cleaner air. The focus adopted by environmentalists, however, varies from the above. In effect, in the name of trade liberalization, competitive pressures present adverse impacts on efforts to set higher environmental standards. Therefore, environmentalists have to pressure their governments to set standards and to impose those standards on their trading partners, as part of their effort to set international standards for environmental protection. Due to the absence of an effective international enforcement mechanism, some countries have to resort to unilateral actions. Under most circumstances, unilateral actions are a violation of existing WTO jurisprudence (Bhagwati and Patrick 1990, and Durbin 1995).

Housman and Zaelke (1992) discuss some options for reducing or eliminating the conflict between trade agreements and environmental policy. The main points of those options are to incorporate environmental considerations into trade agreements. For example, the former GATT did not view a party's application of lower domestic environmental standards, that allow the party's industries to externalize their environmental costs, as a subsidy (or dumping when the product is exported), that could be countervailed by another party whose industries are harmed by the subsidy (or dumping). Some options suggest modifying or interpreting GATT Articles VI and XVI and the Subsidies Code to permit the imposition of countervailing duties or antidumping duties to counter such practices. However, Housman and Zaelke argue, quantifying the effect of differing environmental standards could pose additional administrative problems beyond those already associated with countervailing and antidumping statutes. Unfortunately, not much progress has resulted from research in this area.

2.6.2 Transnational Pollution and Trade

The recent interest in transnational pollution and trade is concentrated on two issues: first, does free trade increase transnational pollution? Second, is "green" trade policy an efficient way to regulate transnational pollution?

Copeland and Taylor (1995b) examine the first issue using an approach different from earlier studies such as Merrifield (1988) and Rauscher (1991b). They develop a multi-good, many-country trade model in a general equilibrium setting. Assuming that global environmental quality is a pure public good whose supply responds endogenously to trade-induced changes in relative prices and incomes, and by dividing the countries into North and South groups, the authors use the model to explore how welfare and pollution levels are affected by free trade in goods and pollution permits, by international income transfers, and by international agreements limiting or reducing pollution emissions respectively. They also demonstrate that in a factor price equalized trade equilibrium, trade raises the level of pollution generated by each Southern country, lowers the pollution level generated by each Northern country, and leaves world pollution unaffected. They also show that if trade does not equalize factor prices, then free trade increases global pollution in a equilibrium under specialization and the supply response to the factor-price movements created by trade leads to reduced pollution in the North and increased pollution in the South. The authors further investigate the effect of income on trade and world pollution and find that the pre-trade world income distribution determines how trade will affect the environment. If the world distribution of income is highly skewed, then free trade increases world pollution; but if countries have relatively similar incomes, then free trade has no adverse effect on pollution.

There is also an extensive literature on the second issue concerning the efficiency of green trade policy. Baumol (1971), Markusen (1975b), and Rauscher (1991b) have shown that it may be in one country's interest to use trade policy in order to reduce transnational pollution from abroad. Recently, Maestad (1998) goes further by arguing that the use of green trade policy may be desirable from a global point of view as well, because such measures may promote global economic efficiency. He assumes: firstly, that the trade provisions are implemented jointly with full Pigouvian taxes on domestic sources of environmental degradation; and secondly, that the trade provisions do not have any direct effect on the environmental policy pursued by a foreign government. Based on the analysis of a two-country partial equilibrium model, the author concludes that when some countries are reluctant to internalize environmental costs, efficiency in the global economy may be enhanced by regulating the trade with these countries; note that Baumol and Oates (1988) also obtain the same result. Efficient green trade policy may take the form of trade restrictions or trade promotions, depending on the type of environmental problem and on whether the domestic net import of the relevant commodity is positive or negative. The policy implication of this study is that international trade agreements such as those formed under the WTO should be revised in order to accommodate the demand for discriminating green trade measures to some extent. This study also shows that the usefulness of green trade policy is not restricted to the transnational pollution case; trade provisions may promote global economic efficiency when some countries take unilateral steps towards solving local environmental problems as well.

2.6.3 Natural Resources and Trade

There are many studies that evaluate the relations between natural resources and trade, e.g. see Withagen (1985), Puttock and Sabourin (1992), and Park and Labys (1999). In fact, the theoretical linkages between natural resources and international trade are many and varied. Research attempting to integrate natural resources and international trade usually captures one or both of the two essential features of the asset nature of natural resources. These include the rate of change of the resource stock over time and /or the long-run equilibrium condition on the rate of return from holding the resource (Dasgupta et al. 1978). There are two general approaches to this integration. The first places trade possibilities into the standard closed-economy model of resource use to determine whether the results obtained from the closed economy carry-over to the open economy. In the second approach, natural resources are added to a standard trade model to determine how they affect trade and whether standard trade theory carries over to economies that have natural resources.

In surveying these linkages, Segerson (1988) summarizes that, intertemporally, the existence of an externality associated with resource use implies a divergence between private and social comparative advantage. As a result, market-determined production and trade patterns are no longer Pareto optimal. The same is true if intertemporal externalities associated with user costs are not fully internalized. She further concludes that even if an intertemporal externality is fully internalized, the dynamic aspects of natural resource use can still affect international trade. In particular, it can: (1) cause resource production and trade decisions to be closely linked to capital markets and thus create an additional link between capital markets and trade; (2) force small countries that are dependent on imports of essential exhaustible resources to export more and more of their agricultural commodities to cover the increasing cost of resource inputs; (3) direct resource-rich countries to increase the degree of processing of natural resources prior to export to avoid rent extraction by resource-poor importers; and (4) increase the possibility of complete specialization due to relative resource endowments or differing rates of time preference.

2.6.4 Hazardous Substances and Trade

Hazardous substances usually refer to those which have a direct or indirect negative impact on environmental quality (pesticide, chemicals, and hazardous wastes for example). Since the 1980s, there is an increasing evidence of potential or actual damage due to exports of hazardous substances. Scherr (1987) and Azevedo (1982) survey the evolution of U.S. regulations of such trade. The main issues in the U.S. involve the listing of ingredients or chemical components of exports and imports, explicit bans on drugs which are domestically prohibited, and procedures for altering importing countries of the export of hazardous substances.

Oates and Schwab (1988) propose four necessary conditions to achieve optimal trade in wastes: (1) the exporting country should inform the receiving country of the content of the wastes and their potential risks; (2) the reservation price must include not only the opportunity cost of the land but also the full social cost caused by the disposal of the waste; (3) transportation costs must incorporate the full social cost of shipping the wastes from the generating site to the destination; and (4) developing countries must effectively enforce environmental regulations to reduce the illegal dumping that creates substantial social costs. Xing and Kolstad (1996) point out that patterns of waste trade include two routes. One route is from a high-income country to a low-income country. The other route is between industrialized countries where the waste flows are from a country with abundant assimilative capacity to the one that has scarce assimilative capacity.

2.6.5 Global Warming and Trade

In the past two decades, academic and policy concerns over the risks of global warming have led to numerous publications addressing this issue. However, there is no discussion about the role of trade in the global warming process. On the contrary, there are many studies on the trade effects of greenhouse gas (GHG) abatement and the use of trade measures to limit GHG emissions in order to slow down the global warming process.

Whalley and Wigle (1991) quantitatively investigate the effect of GHG abatement on the terms of trade between fuels and final goods. They illustrate that the terms of trade between fuels and final goods are potentially sensitive to GHG abatement. Abatement is bound to lower the supply price of carboniferous fuels relative to business-as-usual, but it will also raise the demand price of such fuels, directly if it is pursued by taxes or tradable carbon permits or indirectly by raising shadow prices if it is pursued by regulation. Burniaux et al. (1991a, b) and Symons et al. (1990) have conducted similar research. These studies also show that the terms of trade between fuels and other goods will be altered no matter how abatement is achieved, but the direction of change depends on whether the (explicit or implicit) carbon tax is collected and kept by consumers or by producers.

The issue of how GHG abatement influences changes in international competitiveness has also received some consideration, e.g. see Glomsrod et al. (1992) and Blitzer et al. (1990). Competitive issues arise if abatement falls unevenly across countries. Unfortunately, the greater the abatement, the higher are industrial costs and the less competitive the economy.

In recent years, various forms of international GHG emissions trading systems have been studied, e.g. see Manne and Richels (1996), and Edmonds et al. (1997). It is believed that emissions trading can bring about substantial potential abatement cost savings compared with abatement measures such as international GHG taxation and quotas. However, one challenge in achieving such benefits in practice is that emissions trading requires an international allocation of emissions rights. International negotiation on this issue would be very difficult. Implementation and enforcement of such an emissions trading system are also a problem in an international setting.

2.7 Pollution Redeployment to Developing Countries

2.7.1 National Environmental Policy and Capital Mobility

The relationship between national environmental policy and capital mobility has been studied extensively since the 1970s, e.g. see Cumberland (1978) and (1981), McGuire (1982), Oates and Schwab (1988), Sinn (1994), Wellisch (1995), and Schneider and Wellisch (1997). It is generally believed that in an open economy, the strictness of a country's environmental policy may influence the country's competitiveness for mobile capital. An earlier investigation into the issue was conducted by McGuire (1982). In order to analyze the movement of capital across frontiers caused by environmental regulation, McGuire incorporates an environmental factor, in the form of effluent output, as an input of the polluting industry into a two-factor-and-two-country Heckscher-Ohlin model. The environmental regulation is represented by the marginal product of the effluent, which is a variable determined by the public. In the absence of regulation the marginal product of effluent is equal to zero. Thus, the effect of the environmental regulation on the polluting industry is equivalent to negative neutral technical progress. That is, for the same bundle of labor and capital inputs, the polluting industry will produce less if an environmental regulation is applied. Therefore, if capital is freely mobile across boundaries, the least differential regulation between countries will entirely drive out the regulated industry from the more to the less regulated economy.

A recent interesting discussion on environmental policy and capital mobility is presented by Schneider and Wellisch (1997). In their analysis, an economy consists of a traded-good and a non-traded-good sector. Furthermore, free capital mobility is allowed between countries. According to the study, given that production technologies are the same in both sectors and the elasticity of substitution between capital and labor is positive, it is unambiguously the case that, in order to keep the outflow of the factor rewards to emissions low, the non-traded-good sector receives relatively more emissions permits. This counter-intuitive result is due to the fact that prices can be adjusted for non-traded but not for traded goods. Suppose that emissions allowances are increased in the traded sector at the expense of the non-traded-good sector, holding the overall emissions level constant. The traded-good sector experiences a capital inflow while the non-traded a capital outflow, and fewer non-tradables will be produced. This drives up the price for non-tradables. Thus, due to the flexible output price for non-tradables, capital inflows into the traded-good sector are not fully offset by capital outflows of the non–traded sector. Restricting the outflow of emissions rents implies a limiting of the inflow of capital, since the implicit factor reward on emissions is part of the interest payments flowing out of the country. Hence the authors conclude that restricting the outflow of emissions rents results in relative generous pollution allowances in the non-traded-good sector.

2.7.2 Environmentally-Induced Industrial Relocation

The "industry flight hypothesis" suggests that since the developed countries impose tougher environmental policies than do the developing countries, polluting industries shift operations from the developed to the developing countries; developing countries thus become “pollution havens.” According to Xing and Kolstad (1996), this hypothesis is based on three arguments. First, environmental policies will increase the production costs of the polluting industries. Second, tough environmental policies discourage new investment away from the polluting industries. Third, since some policies directly confine the range of products or the inputs of production, producers have to relocate their production in other areas.

However, neither theoretical nor empirical studies in most cases support the industry flight hypothesis, i.e. for overviews, see Dean (1992), Xing and Kolstad (1996), and Ulph and Valentini (1997). Ulph and Valentini (1997) probe the issue using a model of two countries, two industries, an upstream and a downstream sector, and two firms in each industry. The authors carry out their analysis through a three-stage game: in the first stage the two countries set their environmental policies; in the second stage the firms in both industries choose how many plants and where to locate; and in the third stage firms choose their output levels, with the demand for the upstream firms being determined endogenously by the production decisions of the downstream firms. Based on their analysis, the authors come up with some surprising results. The effect of environmental policy imposed in one industry can sometimes be positive: i.e., a country imposing a small emissions tax can attract firms from other industries to locate in that country. In addition, environmental policy may have important hysteresis effects: once a country’s emission tax is high enough to drive firms out of the country, the country is unlikely to attract the firms back by lowering its emission tax. The authors attribute these results to the multiple-equilibrium feature of the models and to incentives for agglomeration.

Leonard and Duerksen (1980), Walter (1982), Pearson (1987), Leonard (1988), Lucas, Wheeler and Hettige (1992), and Low and Yeates (1992) empirically investigate the industry flight hypothesis. Leonard and Duerksen (1980) analyze trade and investment data to find whether the differences in environmental control costs have led to industrial flight toward developing countries. Their study shows that, instead of developing countries, the receivers of most foreign investment in polluting industries such as paper, chemicals, metals and petroleum refining are other industrial countries. Moreover, the percent of U.S. foreign direct investment in polluting industries in developing countries compared to developed countries did not show a significant increase over time. Hence they conclude that there is no evidence of the flight of U.S. industries to developing countries. Based on his study on the trend in foreign direct investment by firms from Western Europe, Japan, and the United States in the 1970s, Walter (1982) reaches the same conclusion. Although there exists a large amount of overseas production in polluting industries, there is little evidence that it has been caused by differing pollution abatement costs and that foreign direct investment is fleeing to countries with less stringent environmental policies. Pearson's (1987) survey also supports the conclusion that there is little evidence of industrial flight to developing countries.

According to Leonard (1988), the industrial flight and pollution haven hypotheses are not convincing because they are based on too static and too narrow a definition of comparative advantage. Therefore, in his case studies of foreign direct investment in Ireland, Spain, Mexico, and Romania, Leonard includes in his analysis factors such as: the product cycle, industrial location decisions by firms, bargaining processes between multinationals and host countries, and development strategies. Again, the author finds no supportive evidence for the industrial flight and the pollution haven hypotheses. The four investigated countries seemed to react in accordance with the pollution haven hypothesis in the 1970s. However, gains obtained from lenient environmental policies were not great enough to change the locational preferences of multinationals since other considerations such as labor supply, infrastructure and political stability appeared much more important in location selections.

Lucas, Wheeler, and Hettige (1992) econometrically test the hypothesis that environmental policies drive polluting industries from the OECD countries to developing countries. In their study two regression models are employed. The first model regresses the toxic emissions density on GDP per capita and a time trend variable. The second regression is the growth rate of toxic emissions density on the growth rate of GDP per capita and an economic structure variable, the ratio of domestic prices to world prices, which is usually considered a measure of the openness of an economy. Though the two regressions reveal that the poorest countries have the highest growth rate of toxin emissions density, the results are insufficient to draw the conclusion that environmental policies lead to a flight of polluting industries to developing countries. The estimates show that economic growth has a significantly smaller effect on toxic emissions in open economies than in closed economies. If the industrial flight hypothesis held, then developing countries with open economies would have experienced a rapid growth of toxic emissions density. Their investigation finds that this is not the case in reality.

Low and Yeates (1992) support the industrial flight hypothesis. The authors examine the worldwide redistribution of polluting industries with two indicators: the share of polluting industries' exports in total world exports and the revealed comparative advantage of an industry, which is defined as the ratio of the industry's share in the country's exports to the industry's share in total manufacturing exports. A country is said to have an advantage in an industry if the industry's revealed comparative advantage indicator is greater than one. According to this study, the world's polluting industries' share of exports in total world exports shrank from 18.9 to 15.7 percent between 1965 and 1988. For all developed countries, this share also declined from 20.4 to 15.9 percent during the same period. From 1966 to 1968, only 11 percent of the 109 countries sampled had a revealed comparative advantage indicator greater than one in their polluting industry. From 1986 to 1988, however, 22 percent of these countries had an indicator greater than one and most of the increase in the percentage was from developing countries. In contrast to the decreasing share of polluting industries (especially in developed countries), the authors conclude that stringent environmental policies in developed countries probably lead to the shift of polluting industries from developed to developing countries.

2.8 Environmental Degradation

2.8.1 Trade and the Global Environment

The close linkages between trade and the global environment hava been widely recognized yet remain heavily disputable, e.g. see Baumol (1971), Grossman and Krueger (1993), World Bauk (1992), French (1993), Bhagwati (1993), Daly (1993), Chichilnisky (1994), Copelead and Taylor (1994), (1997), and (1999), Perroni and Wigle Taylor (1994), Lopez (1994), and Selden and Song (1994). In cases such as the shipment of low-cost tropical timber from Malaysia to Japan, and the U.S. exportation of lead car batteries to a plant near Sao Paulo, one could infer that trade affects the global environment negatively. However, in many other cases, world trade has demonstrated positive environmental effects as well. For example, fuel-efficient Japanese cars not only reduce air emissions in the United States but also force U.S. manufacturers to develop more fuel-efficient models. French (1993) summarizes that, for better or for worse, trade and trade-induced integration of the world economy are shaping global environmental trends in at least three ways. First, trade intensifies the environmental impacts of domestic production by expanding international markets. Second, trade makes it possible for countries to obtain from other countries the desired products that are domestically either unavailable or protected by strict laws and hence effectively pass the environmental effects of consumption to someone else. Third, since national environmental policies and even some international environmental treaties are often attacked as “nontariff barriers to trade”, efforts to restore environmental quality within countries and to protect the global commons, such as the atmosphere and the oceans, are erroneously misjudged.

In the debate over the environmental consequences of free trade, Bhagwati (1993) argues with Daly (1993) that environmentalists are wrong to fear the effects of free trade because both trade and environmental protection can be advanced by imaginative solutions. In responding to the widespread fear among environmentalists that free trade accelerates economic growth and that growth harms the environment, Bhagwati points out that the fear is misplaced since growth enables governments to tax and to raise resources for objectives such as pollution abatement and the general protection of the environment. For instance, rich countries today show greater concern about the environment than do poor countries. In addition, an empirical study by Grossman and Krueger (1993) also shows that some environmental quality indicators improve as income increases. Therefore, in Bhagwati's opinion, international trade should generally help protect the environment, rather than harm it.

On the other side of the debate, Daly (1993) contends that the free traders seek to maximize profits and production without taking into consideration social and environmental costs. He further argues that by separating the costs and benefits of environmental exploitation, international trade makes the comparison between them more difficult and hence may mislead economies beyond their optimal scale. In this case environmental costs would rise faster than would any production benefits and the economy would enter an anti-economic phase that impoverished rather than enriched itself. What's worse, Daly points out, since evidence shows that we have already passed that point, the faster we run the farther we fall behind.

Chichilnisky (1994) addresses the trade and the global environment issue in a different way. She thinks that the problem reflects a North-South dimension. Developing countries in the South tend to over-produce and export environmentally intensive goods even if they are not well endowed with them. Developed countries in the North, on the other hand, tend to over-consume, even if trade equalizes all traded goods and all factor prices worldwide. According to Chichilnisky, the patterns of North-South trade in the global economy can be explained by differences in property rights, a factor previously neglected in the literature on trade and environmental issues. Her analysis proves that, if the South has ill-defined while the North has well-defined property rights, this property right difference can create the above-mentioned patterns of trade between the North and the South, even if the two region were identical in technologies, resource endowments, and preferences. She also examines some environmental policies and shows that taxing the use environmental resources in the South is not always reliable since it can lead to more over-extraction if the resources are exploited using labor from a subsistence sector. The author suggests that property-rights policies may be more effective for improving environmental and trade linkages.

2.8.2 Trade-Induced Environmental Degradation

As discussed in the previous section, in response to Bhagwati's (1993a) argument that trade promotes economic growth and that growth improves environmental quality, Daly (1993a) proposes that trade can induce environmental degradation and that degradation can lead to income losses and these income losses can result in further environmental degradation. Copeland and Taylor (1997, 1999) refer to Daly's conjecture as the "trade-induced degradation hypothesis" and work out a theoretic framework for this hypothesis. The authors examine the environmental consequences of trade by studying the role that trade plays in industries that are not only spatially separated but also functionally incompatible. They base their analysis on a simple two-industry dynamic model. Two incompatible industries are assumed to be a polluting manufacturing industry compared to an environmentally sensitive industry. If there is no trade, the productivity of the environmentally sensitive industry will be harmed by the production of the polluting manufacturing industry. Once trade exists, the two incompatible industries can move away from each other. Hence, trade can help to reduce cross-industry production externalities and to improve global productivity gains. However, all countries do not always benefit from any increase in global productivity, since changes in productivity can cause changes in terms of trade. The authors show that, if the share of world income spent on polluting goods is high, the environmental effects of trade will be positive in case of two identical, unregulated countries. When that share is low, trade may worsen environmental degradation and result in a real income loss for the polluting goods exporting country.

Lopez (1994) investigates the economic growth, trade, and environmental degradation relationship in a different setting in which unilateral trade liberalization in a small open developing economy is focused on. The study employs a neoclassical model with assumptions that have been widely applied to conventional general equilibrium and growth analyses (such as the existence of an aggregate function of capital, labor and technology, and constant return to scale of the production technology). In the macro production function environmental resources are incorporated as input factors represented by the level of pollution. The results of the analysis show that the stock effects of environmental resources on production and whether producers internalize such effects are closely related to the impacts of economic growth and trade liberalization on the environment. If and only if individual producers internalize the stock feedback effects on production, will economic growth and trade decrease environmental degradation. If environmental factors do not have stock effects on production, economic growth can harm the environment when preferences are homothetic. In the non-homothetic case, the level of the elasticity of substitution in production between conventional and environmental factors and the relative degree of curvature of utility in income inversely affect the relationship between economic growth and environmental degradation. That is, the lower are the former, the worse the degradation that growth brings about.

Empirical studies on this growth, trade, and environmental degradation issue are few and most draw similar conclusions. The World Bank (1992) concludes that international trade as such cannot be regarded as a cause of environmental degradation, but what causes this degradation is the absence of appropriate environmental protection policies. And indeed, trade could improve the allocative efficiency of environmental goods among and within countries and hence reverse environmental degradation, if environmental costs are adequately internalized by removing domestic and international distortions. Lucus, Wheeler and Hettige (1992) focus their empirical study on air pollution and economic growth using data from both developing and developed countries over 1960-1988. The authors find that air pollution, in general, does not decline with economic growth. Specifically, the income effect on pollution intensity tends to be negative in more open countries while it is positive in closed economies. However, total emissions increase with income even in the most open countries, though in these countries pollution intensity declines. Since the openness of an economy directly reflects its extent of trade liberalization, this study implies that even though trade may not improve the environment, it at least does no harm to the environment.

Perroni and Wigle (1994) have developed a numerical general equilibrium model of the world economy with local and global environmental externalities to examine the effect of trade on environment degradation. The authors group countries into North America (U.S. and Canada), other developed countries, and low and middle income countries. Population, trade, demand, and value-added data used in model calibration stem from 1986. Perfect competition and capital immobility are assumed in the analysis. In addition, three trade-policy scenarios--benchmark trade barriers, free trade, and trade wars, are designed for simulation. The numerical results of the study clearly show that compared to environmental policies, trade policies have little impact on environment quality. Though free trade may more or less deteriorate the environment, its relative contribution to environmental degradation is quite small. The study also suggests that it would be very costly to use trade measure for environmental purposes.

2.9 Factor Rewards

2.9.1 Capital and Labor Rewards

The costs incurred by environmental policies can be passed forward to the consumers of the polluting products, and/or backward to their factors of production. It seems, however, that the issue of how environmental policies affect factor rewards has not yet received much attention in literature. Moreover, studies on the issue have been theoretical and general equilibrium in nature, e.g. see Yohe (1979), Siebert et al (1980), McGuire (1982), and Merrifield (1988). Another common feature of these studies is the use of a two-commodity and two-sector framework in which one sector is polluting and the other nonpolluting. Siebert et al (1980) is an exception, and assumes that both sectors generate homogenous pollution. More often, pollution or environmental factors are incorporated in these studies as a production input into the polluting sector.

Yohe (1979) takes such an approach in his closed economy analysis. At first, he examines the incidence of stricter pollution standards on labor and capital rewards, given the assumption of fixed output prices in both sectors. With prices fixed, Yohe concludes that real returns to capital and labor move in opposite directions and that the shadow price of pollution increases when environmental policies become more restrictive.

Especially, if the non-polluting sector is labor (capital) intensive, the transfer of production factors from the polluting to the non-polluting sector leads to a higher capital-labor ratio and an increase (decrease) in labor reward, and at the same time a decrease (increase) in capital reward. Further, the author re-examines the issue by setting output prices flexible and derives the same qualitatively identical result as with the presumption of fixed output price, but the magnitude of the effect of more restrictive pollution control on capital and labor rewards varies with the relative and weighted price elasticities of demand in both sectors.

Based upon almost the same framework as Yohe (1979), Siebert et al (1980) investigate the case where both sectors produce homogenous emissions. Their study shows that if one sector is strongly pollution intensive, while the other is strongly capital (labor) intensive, then a tighter pollution standard results in a rise (decline) in the capital reward and a decline (rise) in the labor reward. If neither of the sectors is relatively pollution intensive, a tighter standard reduces the rewards of both factors.

McGuire (1982) also develops an approach similar to Yohe's (1979) concerning the environmental regulation and factor reward issue. However, he also introduces international trade and emissions damages, and assumes a fixed marginal social cost of pollution. Prior to the incorporation of international trade, McGuire analyzes the effect of regulation on factor rewards in an autarchic equilibrium. It is not surprising that the author comes to conclusions close to those of Yohe (1979) and Siebert et al (1980): environmental regulation results in movements of capital and labor rewards in opposite directions and the rewards of capital and labor depend on the elasticity of demand for the polluting good and on the relative capital/labor intensity of the polluting good in comparison with the non-polluting good. After introducing international trade, the author separately analyzes the regulation effect on factor rewards in a coordination and an uncoordition case. When the two countries coordinate, a uniform shadow piece is levied on emissions in the production of the polluting sector. The analysis demonstrates that the coordinated control does not change the outcome of factor price equalization obtained in the autarchy case. In the uncoordination case, however, factor price equalization no longer exists; it is destroyed by non-uniform regulations between the two countries. The author concludes that, for a small country with no influence over world commodity prices, pollution control regulation definitely decreases the reward of the factor used intensively in the production of the polluting sector and unambiguously raises the reward of the other factor. For a large country, its uncoordinated regulation will increase the world price of the regulated commodity, and the reward of the factor used intensively in the production of the regulated commodity will unambiguously enjoy a worldwide increase.

Merrifield's (1988) research follows up and advances the above studies. The model used by Merrifield is basically the same as that of Yohe (1979) and McGuire (1982). However, the author additionally allows pollution, commodities, and capital to be internationally mobile, and output prices and factor rewards to be endogenous. The author also improves the model by including more restrictive emissions control equipment standards. In a general case, the analysis reveals that a production tax will cause changes in factor rewards. Specifically, if a country's exporting commodity is taxed, the consumer's price rises and the producer's price falls, and both capital and labor rewards decrease in that country. If a restrictive abatement equipment standard is adopted in either country, the relative scarcity of products in the adoptive country may increase. The scarcity will be reduced if the country can absorb the excess capital supply released from the reduction in pollution. Therefore, once the production of pollution control equipment is capital intensive enough, the excess capital supply will lower the rewards for capital and raise the rewards for labor in both countries. If the non-acting country's share of total income is large and there is easier substitution of capital for labor in the acting country, labor rewards may decrease. The author also applies his analytical framework to the North American acid deposition issue in order to illustrate his theoretical results.

2.9.2 Resource Rewards

According to the Heckscher-Ohlin theory, resource endowment is the key factor leading to trade. However, the conventional Heckscher-Ohlin model usually includes only two resource factors of production, namely labor and capital. Some economists now recognize that other resources such as the environment, as well as other productive resources such as land and other natural resources, should be taken into consideration for more realistic models and theories, i.e. see Abbott and Haley (1988), Lopez (1994), McGuire (1982), Merrifield (1988), and Yohe (1979).

Environment as a resource has been incorporated into the Heckscher-Ohlin model as a factor of production by Yohe (1979), McGuire (1982), and Merrifield (1988). Lopez (1994) uses a different neoclassical general equilibrium set up but the treatment of the environmental resource is about the same. The environmental factor is usually measured in those analyses in physical quantity of emissions to the environment as a result of production. The relationship between environmental policies and the prices of this factor revealed in those studies is rather straightforward. In the case of no environmental policy, firms can discharge whatever amount of effluent generated in production into the environment without any costs. Thus, the price of the environmental factor is virtually zero. With an environmental policy, firms will use the environmental factor to the point where the value of its marginal product is equal to its price, which is determined by the marginal costs of pollution abatement. In general, the stricter an environmental policy, the higher the marginal abatement costs and hence the higher the price of the environmental factor. Obviously, those studies underestimate the price of the environmental resource because they neglect the marginal social costs of pollution. A reasonable determination of the environmental resource price should include not only the marginal costs of abatement but also the marginal social costs of pollution.

There is little evidence on how environmental policies affect the rewards to land and other natural resources such as energy and materials when treated as factors of production. Lopez (1994) does model land and forest as two productive factors in his analysis. However, the author's interest is mainly on the stock feedback effect of those resources on economic growth and trade liberalization. The rent of land and the rewards of forest remain unconsidered.

3. METHODS OF ANALYZING THE INTERACTIONS

3.1 Problems of Measuring Trade and Environmental Interactions

Among the various environment and trade issues reviewed above, the results of attempts to analyze them have lacked robustness, e.g. Smith and Espinosa (1995), Copeland and Taylor (1995), and Perroni and Wigle (1994). This has led more recently to studies focused on developing and applying more effective quantitative approaches. Such efforts, however, have encountered a number of difficulties. First, any attempt to model trade and environmental interactions requires an interdisciplinary approach and hence knowledge of many independent subjects such as economics, environmental science, international relations, and scientific law. Second, not much theoretical research has been quantified sufficiently to provide functional relations for hypothesis testing. Third, little empirical evidence exists globally concerning the degree to which economic activities such as trade affect the natural environment, and how individuals value environmental quality. Fourth, it is very difficult to link economic to physical dimensions, that is, to define and to estimate unambiguous indicators for environmental effects, specific environmental factors, strictness of environmental policy, or even of trade strategies. This problem includes the suitability and availability of comparable environmental data and indexes at the global level. And fifth, where it is possible to test qualitative relations, the nonlinear and other confounding effects make it difficult to apply conventional parametric or nonparametric test statistics.

Nonetheless, researchers have attempted to evaluate important environment and trade issues. The methods they have employed appear to concentrate on the following modeling approaches: computable general equilibrium (CGE) models, international trade models, input-output models, welfare models, game theory models, optimization models, spatial GIS models, and econometric models. Below we review each of these methods and discuss their applications in an environment and trade context. The results concerning possible policy implications also are discussed.

3.2 Computable General Equilibrium Models

3.2.1 Market CGE Models

Computable General Equilibrium (CGE) models have been frequently used in studies of this kind, e.g., see Lee and Roland-Holst (1994), Perroni and Wigle (1994), Dessus and Bussolo (1998), Davies et al. (1998), Felder and Rutherford (1993), and Beghin et al (1997). CGE models have evolved from linear programming-based planning models. These models describe Walrasian equilibrium with many goods and factors. Typical market models use production structures based on profit-maximizing producers and demand structures derived from utility-maximizing consumers. The general equilibrium theory employed is the same as in trade theory, where open economies are modeled. A prominent advantage of CGE models lies in the possibility of combining detailed and consistent real-world databases with a theoretically sound framework.

Perroni and Wigle (1994) have constructed a CGE model of the world economy with local and global externalities to investigate the impacts of international trade on environmental quality. Their results show that, though free trade may have a negative impact on environmental quality, its relative contribution to environmental degradation is very small. The authors also find that the magnitude of the welfare effects of environmental policies is not significantly affected by changes in trade policies. What's more, the size and distribution of gains from trade liberalization appear to be little affected by change in environmental policies.

Dessus and Bussolo (1998) have employed a CGE model to examine whether there is a trade-off between trade liberalization and pollution abatement in Costa Rica. Unlike previous analyses, their model embodies a high level of disaggregation for pollutants, products, sectors, and types of households. They also explicitly include dynamic features in the model to reveal the temporal interdependencies of environmental and trade policies by comparing the trends of outputs and emissions obtained from different scenarios. Furthermore, their model allows for substitution between nonpolluting and polluting factors which other similar studies usually fail to include, e.g., see Lee and Roland-Holst (1994). Using this model, the authors show that further integration of Costa Rica into the world economy presents a great risk of environmental degradation if not accompanied by voluntary environmental reforms. These reforms could achieve significant pollution abatement without hampering economic growth or international competitiveness through targeted fiscal policies related to the utilization of polluting goods. Moreover, free trade combined with appropriate effluent taxes enhances factor reallocation towards competitive industries, and hence growth, while significantly abating emissions.

It should be noted that CGE models examining the relationship between environment and trade have mainly concentrated on energy and carbon dioxide emissions, largely because these allow significant economy-wide effects to be found, as the required policy interventions are quite severe. A disadvantage of CGE market models is their complexity in computation and difficulty of validation.

3.2.2 Non-Market CGE Models

In general, past efforts to incorporate non-market environmental resources into CGE models have encountered a number of problems. The first arises from being able to specify only a limited role for environmental resources to be included in the behavioral relationships of a typical aggregate economic model. For example, some models introduce environmental resources as providing a separable contribution to individual well-being (Perroni and Wigle 1994, Ballard and Medema 1993). However, this separable specification assures that commodity demand, and hence relative prices, will not be affected by preference-related substitutions between marketed goods due to changes in environmental resources. The second problem is that most of those models have no spatial dimension that would distinguish the differential environmental impacts of production activities occurring at different locations. These studies would suggest that none of the available CGE trade models are capable of consistently linking the value of environmental resources to consumer preferences.

Responding to this challenge, Espinosa and Smith (1995) have developed a composite non-market and CGE model (NM/CGE) for the European Union, the United States, Japan, and a single region for the rest of the would. This NM/CGE model advanced the Harrison, Rutherford, Wooton model (HRW1--Harrison, Rutherford, and Wooton 1991) by incorporating the morbidity and mortality effects of three air pollutants: sulphur oxides (SO_x) as a transboundary externality, particulate matter (PM), and nitrogen oxides (NO_x) as sources of local externalities. Other important modifications made to HRW1 include: (1) replacing the Cobb-Douglas with Stone-Geary utility functions for aggregate consumers in each region, (2) introducing nine air pollution-induced morbidity effects as translating effects on each household's subsistence parameter for services, and (3) introducing an explicit set of pollution generation and dispersion models for each of the three air pollutants. Each of these modifications has been introduced so that the model's initial calibration is maintained.

This NM/CGE model distinguishes itself from market CGE models by allowing existing non-market valuation estimates to include a specification for consumer preferences that allows changes in atmospheric emissions to diffuse in different amounts in each region and to exert feedback effects on market demands. Specifically, the authors examine the importance of both sets of impacts, market and non-market, on Hicksian welfare measures by comparing the results of model specifications with and without environmental feedback effects to evaluate scenarios that combine trade liberalization with environmental degradation. Two scenarios are used in their analysis: (1) a pure trade scenario which considers a 50 percent reduction in nontariff barriers for all trade between UK and the other EU regions, and (2) a composite scenario which combines this reduction in nontariff barriers with an increase of 25 percent in the emission rates for all three pollutants for the durable manufacturing sector in the UK. Their simulation results indicate that the impact of environmental effects on the economic variables examined such as GDP and prices, are not great when the policy scenario focuses on parameters linked to market transactions. When the mortality effects of pollution are combined with those of morbidity, the impact of removing trade barriers produces greater change in GDP (19.8 vs 18.9 percent). In the composite scenario, the analysis clearly shows the same response. That is, in the absence of a model that accounts for emission changes, the reduced trade barriers would be counted as welfare-enhancing. However, when taking into account the environment, including both morbidity and mortality effects, that judgment changes. The authors further point out, that even if we limit our attention to the morbidity effects of the increased pollution, the environmental feedback effects from the joint change of trade barriers and emission rates are important.

The NM/CGE model provides a novel and useful framework for analyzing trade and environment interactions. However, the uncertainty and complexity of non-market valuation hampers it from having wide-scale applications.

3.3 International Trade Models

3.3.1 The Heckscher-Ohlin Model

The Heckscher-Ohlin (H-O) trade model, based on neoclassical supply-side theories, leads itself to environmental applications. The equilibrium formulation of the model includes two commodities, two factors of production (labor and capital), and two countries. Factors are assumed to be perfectly mobile within a country but immobile between countries. In addition, identical technologies and identical demands between countries are also assumed. The main tenet of the model is that a country will export the particular commodity that most intensively uses its relatively abundantly-endowed factor. Comparative advantage and trade, therefore, are determined by differences in factor endowments among countries. From this model, three additional theorems are derived: the factor-price-equalization theorem, the Stolper-Samuelson theorem and the Rybczynski theorem (Markusen et al 1995). All these theorems form the core of modern trade theory and have been widely used in international trade analysis.

Many theoretical and empirical studies on trade and environment issues are based on modifications of the H-O model, e.g. Walter (1975), Grubel (1976), Yohe (1979), McGuire (1982), Merrifield (1988), Siebert (1992), and Diao and Roe (1997), among others. One modification is to treat environmental damage avoidance as a third good in the model, the output of which competes with the production of other two conventional goods. Walter (1975) demonstrates that that general equilibrium exists in such a three-good H-O model and increased pollution abatement reduces the output of the conventional goods but raises social welfare. However, actual application of this approach to examine the terms of trade, the volume of trade flows and the efficiency of environmental policy has been limited.

Another modification following Grubel (1976) assumes that environmental pollution is associated with either the production of one of the two goods or with the consumption of a good. Hence, environmental pollution results in either a shrinkage in a country's production possibility frontier or a reduction of the consumption level of the pollutive good due to the implementation of proper environmental protection measures. Based on this approach and using general equilibrium analysis, Grubel obtains many useful results about the impact of environmental policy on international trade and welfare. Diao and Roe (1997) have followed the same approach, but unlike Grubel (1976), they assume non-homothetic utility to explain changes in the demand for the non-pollutive good when income increases. Both studies conclude that countries have incentives to adopt environmental policies and, in the large-country case, a country adopting environmental policies may benefit from an improvement in its terms of trade.

And still another modification introduces environmental elements as input factors of production, e.g., Yohe (1979), McGuire (1982), Merrifield (1988), and Siebert (1992). McGuire (1982), for instance, in his study of the impact of environmental regulation on factor rewards, assumes that one good is production-pollutive and thus environmental usage or depletion represents a productive factor of that good. Efficient environmental regulations should make the value of marginal product of the environmental factor equal to its shadow price. A similar treatment is also employed by Siebert (1992), where environmental scarcity is interpreted as a factor of production in the H-O model. If both trading countries' environmental policies find the correct shadow price of their environmental factor, the environmentally rich country will have a comparative advantage to produce and to export the pollution-intensive good, while the country with limited environmental resources will export the less pollutive good. Merrifield (1988) models the environmental factor in a more detailed way. Both emissions and pollution abatement equipment appear as inputs in the commodity production functions of both economies. This approach is thus able to capture the economic effects of tighter abatement standards.

3.3.2 Empirical Trade Models

Among the empirical applications of the H-O model to environmental issues, the cross-sectional Heckscher-Ohlin-Vanek alternative (H-O-V) has proven popular, e.g., see Bowen (1983), Leamer (1984), Brecher and Choudhri (1988), Murrell (1990), Trefler (1994), and Leamer and Levinsohn (1995). The H-O-V model is a multi-factor and multi-commodity extension of the H-O model (Vanek 1968, Melvin 1968, and Leamer 1980). According to the H-O-V theorem, in reasonably generalized cases, differences in relative factor endowments still determine comparative advantage. Unlike the H-O theorem, comparative advantage in the generalized case refers to the patterns of trade in factor contents rather than in commodities. The practical significance of the H-O-V theorem is in the establishment of the relationship between the net exports of commodities and the endowments of factors. Therefore, it is unsurprising that an empirical H-O-V model usually consists of a set of linear equations explicitiy expressing this net-export and endowment relationship.

An econometric application of the H-O-V model to trade and environmental issues made by Tobey (1990) extends the conventional H-O-V model by introducing a qualitative variable into the net-export and endowment equation to represent the environmental endowment measured by the stringency of environment policy. Other resource endowments include capital, different types of labor and land uses, coal, minerals, and oil. Five aggregate pollution-intensive commodity groups are examined: paper, mining, iron and steel, nonferrous metals, and chemicals. Econometric estimation of the resultant equations is based on observations from 23 countries (13 developed and 10 developing countries). In addition, the author also investigates the trade effects of environmental policy by examining the signs of the estimated error terms when the variable of the environmental endowment of a country is excluded in the H-O-V system. The most important finding of this study is that the strict environmental policies adopted by developed countries in the late 1960s and early 1970s do not have measurable impacts on patterns of world trade.

Another empirical model successfully applied to international trade is the gravity model, e.g., see Tinbergen (1962), Hamilton and Winters (1992), van Beers and van den

Bergh (1997), and Wall (1999). The gravity model of trade explains trade flows between two countries based on income, population, and measures of economic and geographic proximity. In a common specification of the gravity model, bilateral trade flows are a log-linear function of the two trading partners' incomes, the geographic distance, and any other factors either promoting or resisting trade between them. Despite its consistent empirical success in explaining trade flows, the gravity model has often been criticized because of its lack of a rigorous theoretical foundation. However, Anderson (1979) and Bergstrand (1985) show that the gravity model can be derived from trade models under certain assumptions, and Deardorff (1998) proves the gravity model to be consistent with some variants of Ricardian and H-O models.

Extending the basic gravity model to include variables describing the stringency of domestic environmental policies, van Beers and van den Bergh (1997) empirically investigate the impact of environmental measures on particular trade flows. In the study, two types of environmental indicators are used: a narrow one, directly relating to economic costs of the environmental policy imposed on producers, and a broad one, made up of environmental indicators, some of which do not result in an increase in producers' economic costs. The authors repeat the empirical test of Tobey (1990) by applying the gravity model with the same environmental policy stringency measure and the same cross-section observations. The authors conclude similar to Tobey that stringent environmental policies have an insignificant impact on trade flows of pollution- intensive industries. The authors also estimate the gravity model with total bilateral trade flows as the independent variable and find that the impact of broad policy indicators that do not directly reveal environmental costs reflected in producer prices on bilateral trade flows is not significant, while more narrow policy indictors that are more directly in line with the "polluter pays principle" do have a significant negative impact on exports.

3.4 Input-output Models

3.4.1 Basic I-O Models

Input-Output (I-O) models have been widely applied to the analysis of economic growth, trade and environmental issues, e.g., see Brody and Carter (1972), Bulmer-Thomas (1982), Leontief (1986), Pasurka (1984), Ozaki et al (1995), Gale and Lewis (1995), Miller er al (1989), van Ierland (1993) and Frechtling and Horvath (1999). Input-output models describe and explain the production and consumption of each sector of a given economy in terms of its relationships to the corresponding activities in all the other sectors. Conventional I-O models (Leontief 1966, 1970) are presented by a set of liner equations which express balances between the total input and the aggregate output of each commodity and service, produced and used during a certain period of time. In addition to static general equilibrium models (Davar 1994), other developments include dynamic models (Leontief 1986 and Duchin 1989), optimization models (Nijkamp and Reggiani 1989 and Kohno 1996), stochastic models (West 1986 and Ten Raa 1995), and extended models (Bulmer-Thomas 1982, Batey 1985, and Batey and Weeks 1989).

Multiplier analysis constitutes an important aspect of I-O model application. Multipliers measure the impacts of exogenous economic changes or policies on endogenous variables such as the total output, employment, and income. One can incorporate only direct effects (intersectoral linkages) into the calculation of total effects, or one can take into account both the direct and induced effects (linkages between the spending of income payments and intersectoral demands). Linkage analysis, also considered an important application of multiplier analysis, consists of two forms. Backward linkages reflect the extent that other primary, intermediate and capital goods are consumed by a given sector and measure the potential stimulus to other activities from an output increase in a given sector. Forward linkages show how the output of a sector is used by other sectors and measure the induced incentive of an output increase in a sector to the output expansion of other sectors. Linkage analysis is often used to explain interindustry investment effects and their impact on income (Hirschman 1958, and Prasad and Swaminathan 1992). However, Stewart et al (1972) and Bulmer-Thomas (1982) point out that this could be misleading since both forms of linkages are not reflected in market prices, and, therefore, indicate the existence of externalities, which could cause the social benefits of an investment to diverge from private benefits.

3.4.2 Trade and I-O Models

There are at leas two approaches to incorporate trade into an I-O model, i.e. see Barker (1972) for a useful overview. The first approach omits prices; early studies by Leontief (1951) and Stone (1962) fall into this category. Usually, exports are exogenously introduced into the model, and imports are determined according to domestic levels of output and balance of payments constraints. Though prices appear in the balance of payments constraints, they are assumed to be constant. Such models can ascertain the sources of comparative advantage and the production structures for international trade. The second approach introduces a price mechanism along with exports and imports, e.g., see Aukrust (1970), Cambridge (1970) and Waelbroeck et al (1970). That is, relationships between imports and domestic output are determined by relative prices instead of constant price coefficients. Exports are also made responsive to relative prices. In addition, relative prices *per se* are allowed to change with other economic variables such as exchange rates. The balance of payments constraints hence can be more effectively described.

Since the 1970s, the use of the international I-O model permits one to explain relationships between one country's imports and another's exports and the reciprocating effects of trade via both quantity flows and price levels, e.g., see Petri (1976), Torii et al (1989), and van der Linden et al (1995). Moreover, the feedback effects of various international trade policies such as tariff reductions and trade liberalization can be conveniently simulated and analyzed, e.g., see Torii et al (1989) and Almon et al (1991). There are two types of international I-O trade models. Consistency models are composed of balance equations for each sector in each country (Petri 1976, and Almon et al 1991 amongst others). Optimization models usually consist of a member countries' total income maximizing objective function and a set of I-O relationship-based constraints, e.g. see Panchamukhi (1976) and Torii et al (1989). In addition to trade policy impact assessment, the latter can also serve as a useful tool for analyzing optimal production and trade.

Bulmer-Thomas (1982) demonstrates that I-O models can also contribute to the investigation of comparative advantage and patterns of international trade in an economic development context. The examination of comparative advantage usually requires that domestic and foreign costs be measured in terms of shadow prices and prefers optimization algorithms. The rationality of patterns of trade are examined using the relative factor content of exports and imports (the ratio of capital to labor content of exports and imports). For a recent application of international I-O models to trade patterns, see Ozaki et al (1995).

Gale and Lewis (1995) also extend I-O applications to include trade liberalization and environmental pollution issues. The authors have developed a detailed I-O model of production and trade in the Mexican economy, where CO_2 emissions are measured by fuel use in production and trade consumption, while free trade-induced change in production and trade is expressed by a change in total emissions. Based on this model, the authors first determine the changes in production and trade that result from the implementation of NAFTA. Then these results are used to estimate the change in in the quantity of CO_2 emissions for each industry. The results suggest that free trade with North America increases Mexico's total CO_2 emissions but it also shifts resources away from more pollutive to less pollutive sectors.

3.4.3 Environment and I-O Models

Extending I-O models to include interactions between the environment and the economy began in the late 1960s, e.g., see Ayres and Kneese (1969), Leontief (1970, 1973), and Leontief and Ford (1972); see Forsund (1985) and Forssell and Polenske (1998) for reviews. The early environmental I-O models are notable for augmenting the technical coefficient matrix with additional rows and columns to describe pollution generation and abatement activities. Typically, each pollutant appears as a row in the matrix and pollution produced in each sector is assumed to be a function of its output. Specific anti-pollution sectors are included in the matrix as columns. These abatement sectors obtain inputs from all economic sectors and at the same time also produce various pollutants. Clearly, the concept of materials balance is essential. That is, materials not embodied in final products must be embodied in emissions of pollutants. Therefore, these models are often used to trace environment-economy interactions and to investigate how environmental policy influence the two-way flow process.

Since the 1970s, as a result of increasing concerns over global warming and other transboundary pollution problems such acid deposition, environmental I-O models have evolved to give special emphasis on energy production and consumption (Leontief et al 1977, and van Ierland 1993, among others). As a response to the challenge of *Limits to Growth* (Meadows et al 1972), Leontief and his co-authors (1977) modeled energy and environmental policy within a detailed global I-O framework. The world economy is divided into fifteen regions. A fixed coefficient I-O model with 45 sectors and including resource requirements, in particular, energy requirements, and emission abatement activities is built for each region. All separate regional I-O models are linked through international trade. An important conclusion of the study is that the availability of energy as well as other resources and requirements for environmental protection are not an insurmountable obstacle to the economic growth of developing countries.

Ierland (1993) employs a non-linear dynamic I-O model to analyze economic, energy, and environmental policy in an open economy. The empirical setting of the model is the economy of the Netherlands from 1950 to 2010 (1950-1988 for parameter estimation and 1990-2010 for policy scenarios). Since the impacts of environmental policy differ substantially among branches of industries due to the fact that the intensities of energy, labor, capital, and pollution, and that the import and export coefficients are not the same for any of the branches, the economy is further disaggregated into separate sectors such that the environmental and energy characteristics of the branches show up clearly. In addition, the model not only includes the most important economic variables for the various branches of industries, it also computes the demand for energy in physical units for different fuel types and for the branches of industries, transportation, households and government. Furthermore, the emissions of carbon dioxide can be directly calculated. This model provides a useful tool for both the "hypothetical" policy makers and the "actual" policy makers to obtain an overview of the impact of different sets of policy measures such as an increase in volume of international trade and a reduction in the level of household taxation, and the impact of the changes in external circumstances such as environmental strategies adopted in foreign countries. Clearly, the model can also be used as a framework for trade and environment interaction analysis.

It should be noted that many applied and computable general equilibrium (AGE, CGE) models used to study economic, trade and environmental analysis actually can become extensions of I-O models by explicitly incorporating a supply and demand system. In those CGE or AGE models, parameters of the behavioral and structural equations are either calibrated to data of certain single year or estimated econometrically, e.g. see Jorgenson and Wilcoxen (1993) and (1990), Hazilla and Kopp (1990), and Whalley (1991).

3.5 Welfare Models

3.5.1 Welfare Analysis and Impact Measurement

Welfare analysis is one of the most important tools for policy assessment and, in particular, plays a critical role in measurement of the impact of trade and environmental policies. To begin with, the existence of externalities makes non-market evaluation crucial for policy impact measurement; welfare analysis provides a vehicle to achieve such measurement, e.g., for overviews, see Freeman (1993) and Cropper and Oates (1992). In addition, trade and environmental policies may result in a reallocation of both benefits and costs among nations and among different interest agents; welfare analysis again provides a useful framework to examine the policy-induced benefit distribution, e.g., see Anderson (1992a, b), Kohn (1991), and Eldor and Levin (1990). Finally, policy impacts can also be measured using the surplus components of welfare, e.g., see Thurman (1991), Just and Rausser (1992), and Haley and Dixit (1988). A policy that leads to an increase in the sum of producers' and consumers' surplus can be considered at least potentially Pareto efficient. The most widely used framework for welfare analysis of policy impact measurement involves both partial and general equilibrium models. See Van Beers and Van den Bergh (1996) for a methodological overview; see Eldor and Levin (1990) for a partial equilibrium example and Thurman (1991) for a general equilibrium example. Extensions to three-sector analysis can be found in Anderson (1992a, b), and Haley and Dixit (1988), among others.

3.5.2 Welfare Analysis of Gains from Trade

Gains from trade are one of the most fundamental issues of international economics. Since being initially examined by Ricardo (1817), it has been widely recognized that a country almost always improves its overall welfare by engaging in international trade, i.e. for important contributions to the issue see Samuelson (1939, 1962). In general, gains from trade are considered to derive from two distinct sources (Markusen et al 1995). The first source is gains from exchange which relate to the fact that countries differ from each other in endowments of goods or in preferences and they can mutually benefit from trading with each other. The second source is gains from specialization which refer to another fact that countries can raise their total production and gain from this production increase by specializing in the goods in which they have a comparative advantage.

While in most cases countries can gain from international trade, welfare analysis reveals that not all agents within countries will necessarily benefit from trade; in fact, some sectors may suffer a welfare loss (Dixit and Norman 1980, and Jones 1956). That is, the distribution effect of trade on welfare can be very uneven. For example, trade makes worse off the owners of resources that are specific to the production of goods that compete with imports (Krugman and Obstfeld 1997). Welfare analysis of the distribution effect of trade has long been a subject of international trade research.

3.5.3 Welfare Analysis of Environmental Policy

Economic welfare analysis of environmental policy serves at least two purposes. In the first place, welfare analysis can provide useful guidance for environmental policy design. Usually, maximizing social welfare and influencing its distribution are considered appropriate objectives of environmental policies, e.g., see Baumol and Oates (1988) and Hennipman (1995). On the other hand, welfare analysis of environmental policy is often used in policy comparison and selection. Cost-benefit analysis is a widely employed tool for this purpose, but it has to be accompanied by measures of externalities, e.g. see Thomas (1983) and Torries (1998). Since environmental policy is closely related to the correction of market distortion induced by externalities, willingness to pay hence turns out to be an important concept in the measurement of welfare costs and welfare benefits

(Freeman 1993 and Field 1994). For other applications of welfare analysis of environmental policy, see discussions in Section 3.5.1 and 3.5.4.

3.5.4 Welfare Model Applications

In section 3.5.2, it was mentioned that in most cases countries gain from trade. A key assumption in this regard is that the production possibility set must be convex in order to guarantee that production is maximized at world trade prices (Markusen et al 1995). However, as long as environmental pollution is concerned, this assumption can be inappropriate since non-convexity may exist in the production possibility set when there are cross-sectoral production externalities (Baumol and Bradford 1972). Intuitively, if a country exports a pollution-intensive good, the environmental quality of that country is likely to deteriorate. The social welfare loss induced by environmental deterioration will reduce, even overcompensate for conventional gains from trade.

The welfare analysis of gains from trade when taking into account environmental degradation and the impact of environmental policy has been a focus of several studies, i.e. Siebert (1977), Siebert et al (1980), and Anderson (1992a, b). Adding to the social welfare function an environmental variable and using a comparative static approach, Siebert (1977) and Siebert et al (1980) examine the gains from trade when no environmental regulations exist. They conclude that if a country exports the less pollution-intensive goods, due to an improvement in environmental quality, welfare gains from trade are actually higher than the traditional measure in which environmental quality is excluded in the welfare function. In contrast, if a country exports the pollution-intensive good, welfare gains from trade are lower than the traditional measure and even negative due to the welfare loss resulting from environmental degradation. Using partial equilibrium and comparative-static analysis, Anderson (1992a) investigates the same case in a small-country setting and arrives at the same conclusion. Further, Anderson (1992a) places the problem in a large-country setting: namely, a country is now large enough to influence world market prices and production abroad. The author shows that if the large country imports a pollutive good, welfare gains from trade are unambiguous but smaller than can be achieved in a small country because of a rise in the import price (the terms-of-trade effect). If the large country exports the pollutive good, welfare gains from trade are ambiguous because of the intertwining of two opposite effects: a negative welfare effect of the export price decrease and increased domestic pollution, and a positive welfare effect of decreased transboundary pollution from foreign production.

Now consider the presence of environmental regulations. Siebert (1977) and Siebert et al (1980) demonstrate that, in a small-country case, if a country exports a production pollutive good, welfare gains from trade increase with the introduction of environmental regulations, if in the initial situation the marginal social costs of the pollutive good production are higher than the export price. This welfare improvement comes from two possible sources: a positive effect of prevented environmental damage and an improvement in the terms of trade. Anderson (1992a) also shows that there are unambiguous welfare gains from trade in the same case provided an optimal environmental policy is adopted. In addition, Anderson extends the analysis to trade in a good whose consumption is pollutive. With the introduction of an optimal environmental policy, welfare gains from trade increase no matter whether the country is an exporter or an importer of the consumption-pollutive good. In the large-country case, so long as the optimal environmental policy is in place, welfare gains from trade will always be positive.

In a separate paper, Anderson (1992b) investigates the impact of liberalizing international trade in coal and food on the environment and welfare with a partial-equilibrium-welfare-analysis framework. In the coal-trade-liberalizing case, the world coal market consists of three groups of countries: (1) the protected industrial market economies where the coal producer price is subsidized to be above the coal consumer price which, due to import restrictions, is above the international price; (2) the reforming centrally planned economies where the coal price is set well below international levels; and (3) other market economies where the average domestic coal price level is assumed to be equal to that in the world market. In the case of liberalizing food trade, similar to the previous case, the world market is assumed to be made up of three country groups: (1) a group of almost autarkic centrally planned economies; (2) a set of rich countries whose agricultural market is protected by their governments; and (3) the rest of the world where the price of agricultural products is relatively lower than other tradeables. By means of diagrammatic partial equilibrium welfare analysis, Anderson shows that with appropriate environmental policies, in both cases, liberalizing international trade is beneficial to the environment and to overall welfare.

3.6 Game-theoretic Models

3.6.1 Cooperative Game Theoretic Models

Game theory and game theoretic models have been applied to the study of various trade and environment issues; for overviews, see Ulph (1994) and Blackhurst and

Subraminian (1992); for recent examples, see Ulph (1996), Ulph and Valentini (1997), Barrett (1997), Abrego et al (1997), and Alemdar and Ozyildirim (1998). Multilateral negotiation and cooperation play an important role in the formation of efficient domestic trade and environmental policies as well as international agreements on trade and environmental issues. The 1997 Kyoto agreement is a good example of such negotiation and cooperation. Cooperative game models, which can provide useful theoretical support for those negotiation processes, distinguish themselves from noncooperative game theoretic models in assuming that binding agreements are indeed possible (Friedman 1986). They also assume that each agent has a clear idea about the outcome that cooperation will bring to them. Other features shared are the existence of leadship and reliance on side-payments and side-sanctions. Moreover, leaders are willing to take cooperative action to maximize their joint net benefit, and hence cooperative equilibrium solutions of the models are sometimes heralded as fair outcomes or Pareto optimal outcomes. It is not surprising that many studies conclude that cooperative outcomes are more efficient than noncooperative ones, e.g. Dockner and Long (1993), Barrett (1997), and Alemdar and Ozyildirim (1998), among others.

Specifications of cooperative game theory models as applied to trade and environmental issues differ in many respects. For example, Dockner and Long (1993) analyze international pollution control strategies with a dynamic two-player game. The players are the governments of two neighboring countries. A dynamic framework helps attenuate the free-rider problem and the prisoners' dilemma type of situation because the punishment of any observed noncooperative behavior can be reflected in this intertemporal dimension. The cooperative game is modeled with a joint welfare maximizing presentation. Quite naturally, Pontryagin's maximum principle can be employed to obtain a solution. Barrett (1997) develops a two-stage, multi-player game to examine the capability of trade measures in the enforcement of international environmental agreements. The players include N symmetric countries (governments) and N symmetric firms (one firm per country). In the first stage, governments set abatement standards, which the firms must comply with. In the second stage, firms simultaneously choose their segmented outputs in response. Here international cooperation can be incorporated in the first stage; the abatement standards in each country are chosen so as to maximize the N countries' joint benefits. Alemdar and Ozyildirim (1998) compose a dynamic two-player North-South trade game model to investigate the positive impact of the North-South trade on the Southern environment and its policy implications due to the presence of transboundary knowledge spillovers brought about through trade. North and South are the two players and the joint potential gains from cooperation are characterized with a weighted sum of the two players' lifetime utilities. Weights are regarded as the distributive parameter of the cooperation benefits and their values can be bargained between the two players in the process of negotiation and finalized in a cooperative agreement. The study also features a general-purpose genetic algorithm to solve an open-loop differential game of infinite duration. The optimal regional trade policies are obtained from the numerical solution.

3.6.2 Non-cooperative Game Theoretic Models

Putting the trade and environment issues within a game setting, players often behave non-cooperatively in order to maximize their individual benefits. For instance, in the absence of supra-national authority to enforce the cooperative solution, multilateral cooperation in international trade and global environmental issues is likely to be sabotaged by free-riding and the Prisoners' Dilemma problem (Barrett 1994a,b and Carraro and Siniscalao 1993). Sometimes, differences in agents' ultimate self-interests can be a source of non-cooperation. Governmental policies are aimed to enhance the social welfare, while firms' strategies usually pursue profit maximization. In addition, there are also cases in which players are unable to make legally binding agreements with one another (for example, antitrust provisions prevent firms from colluding). For these and other reasons, non-cooperative game theoretic models have been the more popular in the application to trade and environmental issues. For overviews, please see Ulph (1994) and Kreps (1990); and for particular studies, see Hoel (1991), Martin et al (1993), Dockner and Long (1993), Ulph (1996), Ulph and Valentini (1997), Barrett (1994b) and (1997), Abreg et al (1997), and Alemdar and Ozyildirim (1998).

Though there are various formations of non-cooperative game theoretic models (see the corresponding discussion in cooperative game theoretic models, since each of those studies includes by contrast a same structural non-cooperative game). The prisoners' dilemma is the most fundamental presentation (Snidal 1985), while Nash equilibrium is the most important criterion of strategies (Myerson 1999 and Mailath 1998). That is, in non-cooperative game theoretic models, each player is maximizing his own private benefit, given the supposed actions of the others, and a solution is obtained only when there exists a strategy array which no player has an incentive to deviate from (Kreps 1990).

In addition to the above applications, non-cooperative game theoretic models have also been used in many other trade and environment issue related analyses. For example, Hauptmann (1982) applies a two-player nonzero-sum non-cooperative dynamic game to the oil embargo problem between OPEC and the oil importing countries; Martin and his co-authors (1993) investigate the implication of different environmental policy options in a transboundary pollution setting with an N-asymmetric-player, nonzero-sum dynamic game model; Ulph (1996) uses a three-stage game model to analyze the relationship between environmental policy and international trade when governments and the producers act non-cooperatively; and Ulph and Valentini (1997) examine the effect of environmental policy on plant location based on a three-stage non-cooperative model with two countries, two industries (one upstream and one downstream), and two firms in each industry. Since various kinds of players such as international organizations, countries, governments and firms are involved, the best strategies for different players derived from those studies can provide useful insights for policy design at different levels.

3.7 Optimization Models

3.7.1 The Search for Optimal Trade and Environmental Policies

Although the relationship between trade and the environment is not uniquely defined, e.g., see Daly (1993a) and (1993b), and Bhagwati (1993a) and (1993b), there is a wide consensus that "on the most fundamental level, trade and environmental policy must meet in the concept of sustainable development. Both trade policy and environmental policy must serve that concept as their ultimate goal" (EPA Trade and Environment Committee 1991). Trade policy helps enhance world economic welfare on the one hand, while environmental policy aims to manage and maintain natural resources efficiently on the other; both consist of the most important part of the principle of sustainable development. How should trade and environmental policies be combined to achieve the goal of sustainable development? In other words, within a sustainable development setting, what are optimal trade and environmental policies? Quite naturally, optimization models can provide a solution to resolving such issues. Potential models must share at least two key features. First, the concept of sustainable development must be concretely or mathematically expressed rather than vaguely stated. Second, the spatio-temporal nature of the trade and environment issue must be captured.

3.7.2 Lack of Applications

Since the fundamental problem in economics is how to make the best use of limited resources, optimization methods are among the most important tools in economic analysis. Indeed, various different kind of optimization models have been used in a wide range of economic research fields, e.g., for overviews, see Wilson et al (1981), Feichtinger (1982), Mills (1984), and Schellnhuber and Wenzel (1988). According to the use of optimization techniques, optimization models can be generally divided into calculus optimization models, programming models, optimal control theory models, and differential game theoretic models. Luptacik and Schubert (1982) build an optimization model for optimal environmental investment decision. The focus of their study is on how to allocate output between consumption and investment in productive capacity and pollution abatement so as to maximize social welfare. The concept of sustainable development and the implication of trade in a growing economy are untouched. In Schellnhuber and Wenzel's (1998), optimization models are created to analyze ecological systems, in particular the analysis of global change, sustainable development, and international equity. However, the role of trade and environmental policies is not discussed. Due to the complexity of the problem, no optimization models aiming to search for optimal trade and environmental policies have been built thus far.

3.8 Spatial Analysis and GIS Models

3.8.1 Spatial Analysis

The spatial nature of economic activities and variables was first put into examination in the early 1950s and spatial equilibrium analysis featured the literature of that time (Enke 1951 and Samuelson 1952). Since the 1960s, spatial analysis in economics has greatly expanded its range of study, varying from spatial equilibrium models for trade, transportation and labor markets, to various kinds of more general models for environmental, energy, and geographical and regional economic analyses, e.g., see Labys, Takayama and Uri (1989), Labys and Yang (1991), van den Bergh, Nijkamp and Rietveld (1996), Nijkamp (1986), and Bockstael (1996).

Spatial equilibrium and price models (SPE) are evolved from the basic neo-classical model and most of them have a programming presentation. Samuelson (1952) was the first to give the SPE a linear programming specification. Takayama and Judge (1964) and Takayama and Woodland (1970) further extended this approach to include simultaneous price determination in a temporal as well as the spatial framework (STPE). In these models, markets and transportation are spatially separated from an equilibrium perspective and therefore spatial quantities equilibrate only when demand prices equal the sum of supply costs and transportation costs. Given transportation cost, domestic demand and supply functions in spatial markets, spatial equilibrium searches for the market-clearing prices in all spatial markets, demands and supplies of all locations, and all exports and imports. For SPE applications see Labys et al (1989) and van den Bergh et al (1996).

Spatial models also serve as a useful framework for environment-energy-economy analysis. They are usually an integration of models of the environmental system, energy system and national or regional economy. These models, in general, consist of the following common components: a macroeconomic model; production and consumption functions; equations revealing the relationships between the energy sector, the rest of the economy and environmental quality; a reference energy supply system describing energy demand as well as energy production and consumption technologies; and a setup reflecting spatially separated regions, e.g. see Lakahmanan and Bolton (1986).

3.8.2 GIS Model Theory

Since the 1980s, geographic information systems (GIS) have found wide applications in resource management and environmental modeling, i.e., for historical reviews, see Goodchild, Parks, and Steyeart (1993), and Maguire, Goodchild, and Rhind (1991); for more recent work, see Fischer, Scholten, and Unwin (1996), Hallam, Salinsbury, Lanfear, and Battaglin (1996), and Goodchild et al (1996).

Model applications in this area comprise two categories. The first or major category can be considered coupling models that link conventional environmental models to a GIS model, where GIS is used as a preprocessing and postprocessing tool, e.g., see Darwin et al (1995), Neganban et al (1996), Lee and Pielke (1996), and Chomitz et al (1999). The second category, which is still developing and not yet broadly recognized, uses GIS as the principal tool or language for more sophisticated spatial and temporal environmental modeling. For an introductory review see Maidment (19960); examples are provided in Frysinger et al (1996), and Keller and Strapp (1996).

Models of the first category seem to be not only much more realistic but also more successful. The advantage of these models is obvious; they utilize the power of environmental and spatial modeling software to model environmental processes and other spatial-natured problems; and they use the power of GIS to fulfill input, output, and other data representation and management tasks such as data sampling and data transformation. A shortcoming of the models is the absence of common data models, structures, and interfaces. Model builders thus frequently have to write programs in source code to create workable linkages. Models of the second category, which attempt to incorporate environmental modeling and spatial analysis techniques fully within a GIS setting, rest in an early, experimental stage.

3.8.3 GIS Model Applications

Since the beginning of the 1990s, spatial GIS models have found some applications in describing the relationships between the environment and agricultural production, e.g., see Carter, Porter, and Parry (1991), Eswaran and Van den Berg (1992), Leemans and Solomon (1993), and Darwin Tsigas, Lewandrowski, and Raneses (1995). The focus of those studies is mainly on the direct effects of climate change on crop production. Carter et al (1991) examined with a GIS the shifts in production of grain maize, sunflower, and soybeans in Europe. Eswaran and Van den Berg (1992) used a GIS derived index of agricultural production based on growing season lengths to investigate the impact of climate change on grain production and grazing in India, Pakistan, and

Afghanistan. With similar methodology, Leemans and Solomon (1993) extended their study to match crop production with global climate conditions. Darwin et al (1995) distinguished their research from those the above by combining a GIS with a CGE economic model. The research divided the world into eight geographical regions and used the GIS to link climate with production possibilities of agricultural products in the eight regions. The CGE model was used to determine the effects of changes in production possibilities on production, trade, and consumption of thirteen major agricultural and non-agricultural commodities.

More recently, Chomitz, Griffiths, and Puri (1999) employed a GIS-based spatial price equilibrium model to study the impact of trade and tax policies on deforestation in the Sahel. Specifically, based on GIS data, spatially disaggregate woodfuel supply was modeled at each one-square-kilometer-gridded landscape cell, which had an associated transport cost for supplying the market. GIS methods were used to compute the economically shortest path to the market, allowing for relative differences in travel cost on and off roads. Market equilibrium was determined annually through aggregate demand and supply equations. A simultaneous equation solution was written in GAUSS to integrate supply, demand, regrowth, and accounting procedures and use a grid search to solve for the market-clearing woodfuel prices.

There are also applications of non-GIS-based spatial analysis to trade issues and to environmental policy issues, e.g., see Van den Bergh et al (1996). Applications of GIS to environmental modeling, resource management, and sustainable development planning include Goodchild et al (1993, 1996), Hallam et al (1996), Despotakis (1991), and Despotakis et al (1993).

3.9 Econometric Models

3.9.1 Trade and Environment Linkages over Time

The interaction between trade and the environment is not an instant process, particularly since the quality of resources deteriorates overtime. This deterioration is recoverable for non-depletable resources but otherwise exhaustion takes place. International trade also is intertwined with the intertemporal processes of economic growth and development. Both development and trade have led to unprecedented natural resource extraction and environmental pollution. For instance, in the past 200 years, the use of land, water, minerals and other natural resources has increased more than ten times (Rotmans 1998). However, the detrimental effects of economic growth, especially of international trade, are usually not immediately appreciated because of environmental assimilative capacity, i.e. see Park and Labys (1999). It is often the case that only after these effects become apparent that public concern leads to the enactment of environmental regulations. Econometric time-series models have been successfully used to investigate the relationship between CO_2 emissions and the use of fossil fuels and to analyze the temporal decomposition and cyclicality of global CO_2 concentrations and emissions, e.g., see Nordhaus and Yohe (1983) and Cohen, Labys, and Eliste (2000), repectively. No doubt, econometric methods based on data recorded periodically or over time can also provide a useful tool to analyze temporal relationships between trade and the environment.

3.9.2 Potential Model Applications

Econometric time series models have a long tradition in analyzing temporal interactions, e.g., for modeling possibilities, see Mills (1990), Granger and Terasvirta

(1994), and Harvey (1994), among others. The basic or univariate models attempt to explain the behavior of an economic variable based only on its temporal history. Typically, models of this kind include autoregressive-moving average (ARMA), autoregressive-integrated-moving average (ARIMA) processes, and autoregressive conditional heteroscedastic (ARCH) models. In multivariate models the joint behavior of two or more variables is explained. These models can capture the interactions, which are considered a distinguishing feature, among economic time series. Commonly used multivariate models are causal models, cointegration models, vector autoregressive (VAR) models, bivariate ARCH, and dynamic simultaneous equation models. Nonlinear time series models refer to models which have a nonlinear presentation (for example, exponential autoregressive models), or in which the conditional variance of the process under analysis is allowed to vary over time (for instance, autoregressive conditional heteroskedastic or ARCH models). These models can be used to describe the non-linear feature of economic time series. Curiously, although time series data provide bases for empirical trade and environmental studies, there are no specific time series applications, e.g., see Robison (1988). However, such applications are not difficult to conceive. For example, with time series data, one can test whether trade causes environmental degradation or not. Or one can also examine the effects of growth cycles on trade and environmental interactions.

4. CONCLUSIONS

Though the theoretical and quantitative approaches employed in the above studies are sufficiently varied to make comparisons among them difficult, together they constitute a body of knowledge that enables us to better understand how and to what extent environmental policies influence world trade and the degree to which interactions occur between trade and the environment. To this end, we have found that environmental policies can have an impact on a country's domestic income and balance of trade and payments. However their impacts on employment are less clear. What's more, their impacts on production costs and prices are still in dispute; theoretically, the enacting of environmental policies increases commodity prices and production costs, but this has not been fully supported by empirical studies, particularly since efficiency gains can occur with the adoption of new technologies. Second, according to conventional trade theory, environmental policies should affect patterns of world trade in environmentally sensitive goods and this would result in loss of comparative advantage. However, this conventional view has been challenged by recent theoretical and empirical studies. Third, the above studies show that impacts of environmental policies on the terms of trade depend on the type of policy and economic conditions under which a policy applies. In some cases, an environmental policy improves the terms of trade, but in other cases, it may deteriorate the terms of trade.

The message these studies have sent to policy-makers is not unreasonable: there is no convincing evidence from empirical studies to support the hypothesis about the negative impact of environmental policy on international trade. Therefore, environmental policies which are usually designed to serve social objectives, at least, shouldn't seriously cause adverse trade effects and might even improve them. However, since the quantitative models employed for studying trade and environment issues are always the result of abstractions and simplifications, it is difficult to directly apply the conclusions obtained from any theoretical or empirical study to other kinds of policy situations. Instead, we should evaluate results employing several different methods, each shedding a specific light on the policy issue of interest, in order to better understand what policy alternatives we have and how they are related to each other.

The messages that these studies have for research and model building also are important. One certainty is that there is a need for both more theoretical models and more quantitative studies. There is still much to be done before we can fully understand interactions among trade, environment, and the economy. For example, our knowledge of the environmental consequences of expanded resource trade is still quite limited, and the extent to which environmental policies can affect trade is still unclear. In addition, major approaches to the problem such as CGE models, GIS analyses or econometric models need to be expanded in the applications area. Moreover, the regional and spatial nature of the environment and trade should be adequately addressed and greater attention should be paid to the needs of data.

No doubt, this area of regional economic analysis will expand and hopefully provide useful insights into global policy making.

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